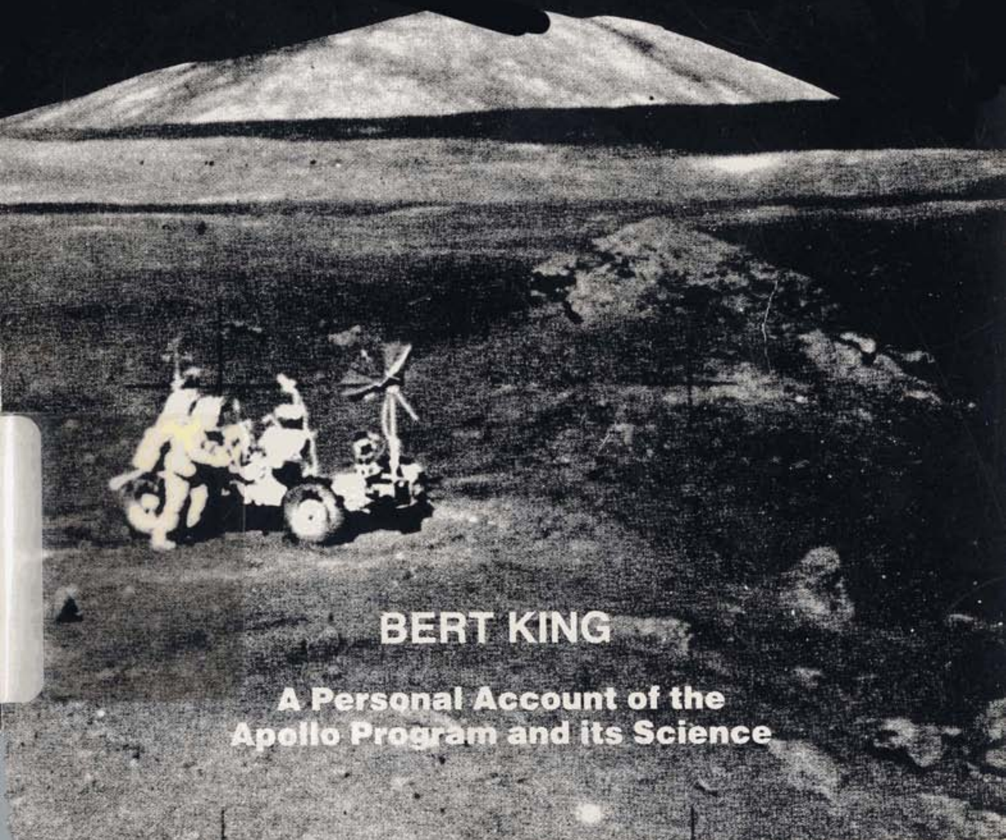
MOON TRIP



BERT KING

A Personal Account of the Apollo Program and its Science

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A Personal Account of the Apollo Program and its Science

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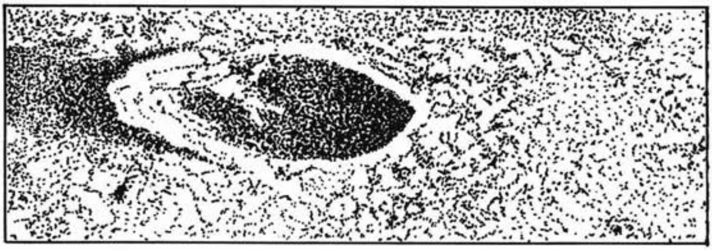
On the Occasion
of the
20th Anniversary
of the
First Manned Landing
on the Moon



Foreword

By now you have recognized that I am not and never have been an Apollo astronaut. Like so many others, my trip to the moon was largely vicarious. I am one of a host of overweight, nearsighted, too-tall, out-of-shape, non-potential astronauts who might have waited for an imagined call that never came.

However, time and circumstance chanced to be favorable, and I was privileged to view the lunar program from a unique internal vantage point. My tenure with NASA spanned six of the most turbulent and productive years of the Apollo program and terminated after the first Moon landing, although my involvement in NASA programs continues to this day. In retrospect, I find with some surprise that I have been involved in space sciences in some way or other for more than 30 years. I have been most fortunate to have

collaborated with many hardworking, bright, and trustworthy colleagues during these years, and I fear this story will not fully convey their dedication and "super-human" effort. Many friends and associates and their important contributions to the lunar program are not mentioned. To you I apologize and hope you will consider yourselves included within the spirit of the tale of events, but length and complexity did not allow me to include everything.

I tell this story from my own personal point of view. Formal histories that fix the blame and grant the glory will be left mostly to the realm of historians, which I am not. Most of us who were involved in the preparations for and execution of the lunar landings and the associated scientific investigations sensed the history of the events in which we participated. With all the media attention at the time it seemed that every possible detail had been recorded over and over. I now find this is nearly true for the "nuts and bolts," but that much of the human side of the story is in danger of being lost.

I am particularly indebted to Clifford Frondel, my teacher and co-worker, who constantly chided me to keep a journal, notes, and records. I did so only in a haphazard way, but it was good advice. Also, I thank John Wood for encouraging me to put the story on paper. It seems that, in my mind, some sequences of events are getting a little muddled, and my "perfect" memory is already not so perfect. I thank the NASA Historian's Office at the Johnson Space Center, particularly Joey Pellarin, for helping me sort out some confusion and for checking on many facts. Constructive comments were offered by Don Wilhelms, Cindy Lottinville, and John Lottinville, who read the entire manuscript, as well as Lisa Read, who read several chapters.

Of course, once we understand where we have been, the big question is: Where do we go from here? Naturally, I have a suggestion!

Elbert A. King
Houston, Texas
January 1, 1989

Prologue

There was never any doubt that I would be a geologist by profession. At the age of five, I collected rocks at various stops on our summer vacation through the western United States and dutifully put them into the backseat of our '35 Plymouth. My parents encouraged this semi-rational activity, and our family developed into a full-fledged nest of rock hounds and mineral collectors. Soon our home in Austin, Texas, was full of specimen cabinets containing agates, petrified wood, and various types of crystal groups, and I was learning a little bit about them. My father, a carpenter and general building contractor by profession, became interested in cutting and polishing stones. He was particularly fond of agates and petrified wood and set up a bench with machines to cut and polish these materials. I soon learned to use diamond rock saws as well as grinding and polishing laps.

The father of one of my childhood friends, Dr. Virgil Barnes, was a geologist with the University of Texas Bureau of Economic Geology. He had been awarded a federal grant to study tektites. Tektites are small glassy rocks that superficially appear similar to pebbles of obsidian or volcanic glass (Photo 1); however, they are not associated with volcanoes, and their origin was in dispute for many years.[1] Some investigators believed that tektites were pieces of the Moon. Barnes needed some tektites cut into thin slabs for micro-

[1]E. A. King, "The origin of tektites: A brief review," *American Scientist*, March–April 1977: 212–218.

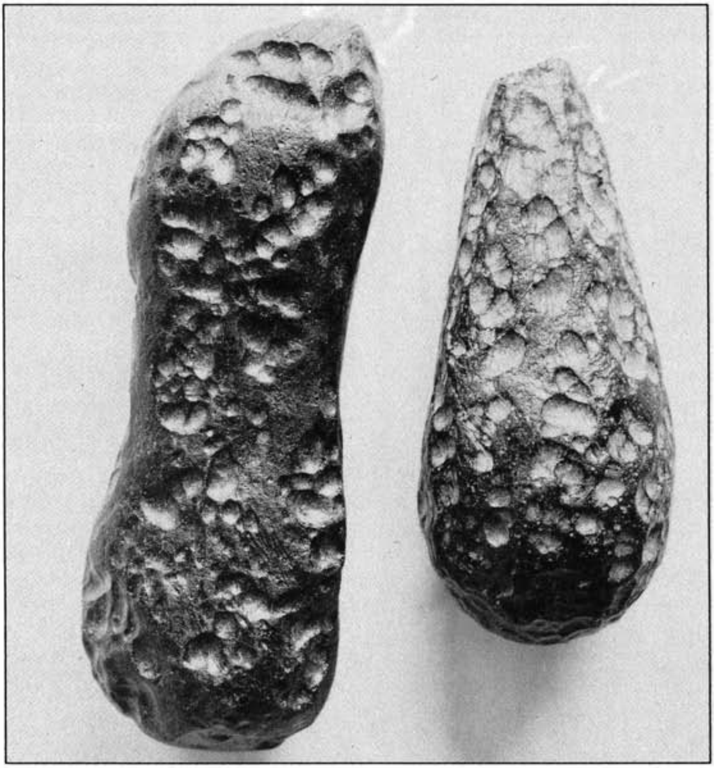


Photo 1. Typical tektites from Thailand. These are very dark brown glass and appear black in reflected light. The length of the largest piece is approximately six centimeters. (Photograph by the author)

scopic examination, but he did not have access to a suitable rock saw. He sent word through his son that he needed some specimens and asked if we could cut them for him. He offered to pay for the work, but we agreed that I could keep a portion of each specimen that we cut for our collection. I picked up the tektite samples from Barnes at his office in an old brick building at the Bureau of Economic Geology, a building I would later get to know very well. I had seen tektites before in museum displays and in the hands of private collectors, but I had never been afforded the opportunity to examine them so closely. I even cut my finger slightly on a sharp glassy edge of a fragment. Strange material to be possible pieces of the Moon. Barnes' tektites were mostly from the Philippines, but a few were from areas in Texas not too far away. It seemed peculiar that pieces of glass from two such widely separated localities should appear nearly identical. I was fascinated by the controversy over their origin. At that time a wide difference of opinion existed about their mode of origin in addition to the argument over whether they had been formed on the Earth or on the Moon. Barnes generously shared his knowledge of tektites with me at the level that a high school student could understand—he was a very patient man.

About a year later, in 1952, a summer job became available at the bureau, and Barnes asked if I might be interested in taking it. The work would entail a variety of tasks, but would mainly involve operating a large rock saw to cut hundreds of feet of oil well cores from deep wells in West Texas for Barnes' paleontologic examination. Of course I was interested! In order to get the job, however, I had to interview with the director of the bureau, Dr. John T. Lonsdale. I was somewhat nervous about meeting Lonsdale, an "old school" gentleman—tall, straight, and cleanly shaven except for a thin moustache. He had served as an artillery officer in World War I and had done a lot of geological field work in Big Bend National Park and other parts of West Texas. It seemed to me that he had been everywhere and done everything, but during our first conversation, he wanted to focus on my interests and experiences,

which seemed very meager indeed. Lonsdale was an extremely gracious and interesting man whose eyes twinkled as he spoke. We had a pleasant conversation for more than half an hour, when he announced that I could have the job. He appeared to be totally fascinated by geology, and I hoped he had formed the same impression about me. Although he tended to be a bit stiff and formal, Lonsdale had put me very much at ease, and I liked him at once.

For the next several years, during my high school and undergraduate days, I worked at the bureau for Barnes and Lonsdale during the summers and part-time during academic semesters. Much of the work was mindless drudgery, but frequently something exciting or interesting came along.

It was at the bureau that I came to know an aging UT doctoral student, John Dietrich, an expert photogeologist who was working on volcanic geology in West Texas. Dietrich later joined NASA and worked at the Johnson Space Center. He became involved in the interpretation of lunar orbital imagery and surface photography and was eventually appointed as curator of lunar samples.

My first face-to-face contact with a meteorite came about through my association with the bureau. One hot summer afternoon while working in the laboratory with Lonsdale, we took a break from some tedious microscope work and began to chat. Lonsdale lit a cigarette—even though he had been trying to quit. I took the opportunity to ask him about a very peculiar rock in a nearby specimen cabinet. He took the rock of eight or 10 pounds from the cabinet and handed it to me. It was covered with a thin cream-colored fusion crust (an atmospheric friction-melted thin layer) on two sides and contained large gray crystals. It turned out to be a fragment of the Peña Blanca Spring meteorite that had fallen in West Texas in 1946. Lonsdale had published the original description and analysis of the stone.[2] As he told me the story of how 150 pounds of rock had fallen on an August afternoon into a partially

[2]J. T. Lonsdale, "The Peña Blanca Spring meteorite, Brewster County, Texas," *American Mineralogist*, vol. 32 (1947): 354–364.

dammed, spring-fed creek that was used as a swimming pool at a ranch headquarters near Marathon, Texas, I was enthralled. The fall of the stone was accompanied by "sonic booms" and occurred within plain sight of a dozen people, some of whom were badly frightened by the event. That a meteorite should choose a swimming pool out of all of West Texas as its place to fall seemed truly remarkable. "Where do meteorites come from?" I asked. Lonsdale told me that not all scientists agreed on the matter, but that most believed they were fragments of asteroids that had been deflected into Earth-crossing orbits by gravitational interactions with Jupiter, Mars, or another large asteroid. I knew the asteroid belt was between the orbits of Mars and Jupiter, but the fact that I was standing there in Austin, Texas, with a rock in my hands that had come from outside the orbit of Mars seemed truly miraculous. Lonsdale said the Peña Blanca Spring meteorite was a very rare type of stony meteorite containing huge crystals of enstatite, a magnesium silicate mineral, and he pointed them out to me. I asked Lonsdale if he had pieces of any other meteorites. He didn't, but he was certain that Barnes did. Barnes was out of town.

For several days I had to content myself with reading about meteorites in textbooks and general publications, but I also looked up both Lonsdale's and Barnes' publications about meteorites. Barnes had described at least three meteorite finds: a stony meteorite from Cuero, Texas; another stone from Kimble County, Texas; and an iron meteorite from Nordheim, Texas.[3] In addition, he had compiled a catalog of Texas meteorites. Not only were the Cuero, Kimble County, and Nordheim meteorites very unlike those from Peña Blanca Spring, they were also different from each other. It seemed curious that four pieces of asteroids should be so different.

When Barnes returned to his office I was impatiently waiting to

[3]V. E. Barnes, "The stony meteorite from Cuero, Texas," University of Texas Publication No. 3945 (1939): 613–622; "The stony meteorite from Kimble County, Texas," University of Texas Publication No. 3945 (1939): 623–632; "The iron meteorite from Nordheim, Texas," University of Texas Publication No. 3945 (1939): 633–644.

see him. I knew he would have lots of mail to catch up on, so I asked to see him on his second day back in the office. I explained how I had developed some interest in meteorites and asked him if I might see some of his specimens. Barnes seemed genuinely pleased by my enthusiasm. He showed me all his meteorites and tektites and allowed me to handle and examine many of them. We spent more than an hour discussing the subjects. I was elated. A well-prepared display in a case or cabinet can be interesting, but the real magic of discovery comes with the intimacy of touch and contact with specimens. Good teachers know this technique and use it shamelessly.

In 1954, during my sophomore year at the University of Texas, I took a required mineralogy class taught by Dr. Fred Bullard. Bullard was a superb lecturer and teacher. I was interested in and well-prepared for the subject, so I excelled in his class. Bullard asked me to serve as teaching assistant for the mineralogy labs the very next semester—quite an honor for an undergraduate. Of course I could not refuse. Before accepting, however, I had to clear it with Lonsdale, who was counting on me for the same semester. Lonsdale understood completely, and I had the impression when talking with Lonsdale that he had already discussed the subject with Bullard.

Working as a teaching assistant in mineralogy labs for Bullard was enjoyable. Bullard was a kind, rational, and fair man. One day while preparing specimen trays for the labs, I mentioned something about meteorites to Bullard. Bullard took me into his office and, to my amazement, showed me several specimens that he had obtained through the years (Photo 2). Meteorites are rare objects, yet three men I knew and respected had samples and had worked with them. They were fascinated by these rare objects as much or more than I was. In any event, I was hooked on the space-related aspects of geology.

Not all my undergraduate classes went so well. I tended to work on the classes I liked and slid through the rest, as many students do. Structural Geology was a required course for geology majors. It wasn't my favorite class by any means, but it was ably taught by

Photo 2. The Rosebud, Texas, stony meteorite (chondrite) showing a well-developed ablation surface due to heating by friction with the atmosphere during entry at high velocity. Maximum dimension is approximately 40 centimeters. (Photograph by the author)

Dr. William Muehlburger, who had recently joined the UT faculty from Cal Tech. Muehlburger, who was a large, very physical man, had played football for Cal Tech. He was an accomplished pianist and was very articulate. Muehlburger also taught the required summer Field Geology course, a stimulating course held in the summer heat of the Marathon Basin of West Texas. The course was physically and mentally demanding and, in retrospect, was exceptional experience for young geology students, though few students were fond of the course. Muehlburger later participated in the astronaut geology training courses both in the field and at the Johnson Space Center. He also led the lunar field geology team that kept track of the astronauts' lunar surface activities during the later Apollo missions. In any event, my undergraduate studies progressed fairly well, although I generated a rather undistinguished academic record with a transcript full of Cs.

During one semester when I was again working part-time at the

bureau, Barnes asked me to accompany him on a field trip to some of the Texas tektite occurrences. He needed an assistant to help with the driving and sample collecting. We would be gone only a few days, so I could probably arrange to miss a couple of classes. Naturally, I was excited! Not only would I get to see where tektites were found, but I might even find one myself. Furthermore, I would be able to discuss meteorites and tektites with Barnes at length. This sounded like a good deal, but to top it off, the bureau would pay me wages for eight hours a day for the duration of the trip and would reimburse me for meals and lodging.

The trip was a grand success. I tried not to be a pest, but I completely exhausted my store of questions after the second day. I didn't find any tektites myself, but Barnes did. I resolved to return to some of the localities later and improve my score. Over the next two years I made several trips to collect tektites, both alone and with my parents, who were still avid rock and mineral collectors. I brought many of the tektites to show to Barnes, especially if they had any unusual feature or were of exceptional size. Eventually, my parents and I collected about two hundred specimens, some from localities previously unknown to Barnes, who carefully recorded them on his maps. In the scientific literature, the argument about the possible lunar origin of tektites was warming up.

In June 1957, I graduated with a B.S. in geology, got married, and was commissioned as an officer in the United States Naval Reserve. My ROTC enrollment caught up with me, and I was assigned to sea duty aboard the U.S.S. *Saint Paul*, a heavy cruiser whose home port was Long Beach, California. My life-style changed dramatically. The Navy wasn't a bad place to be. I learned a lot about people, politics, and bureaucracy, but it didn't seem necessary to study these subjects full-time for two years. I could not imagine doing this for the rest of my life. I presumed large corporations probably worked much the same way. If I ever got out of the Navy, I resolved to be a damned serious graduate student.

I was released from active duty in the Navy after 22 months. No conflicts, police actions, or wars occurred while I was on active

duty. I had been very lucky. I was conditionally accepted to geology graduate school at UT because of my mediocre undergraduate performance. However, I would not be taking any classes until the fall semester, and I desperately needed a job in order to support myself and my young family. I went to see Lonsdale at the bureau. Lonsdale was glad to see me and agreed to put me on the payroll right away. He wasn't exactly certain what I would be doing but was sure he could find plenty for me to do. I was relieved. It felt good to be back in Austin in familiar surroundings and working with people that I already knew well.

My graduate work at UT progressed the way it was supposed to. I worked hard and did well. My master's thesis involved a combination of field work, stratigraphy, and sedimentation. My interest in tektites and meteorites continued, and I made many friends among the other graduate students. One of these was Uel Clanton, who was working with clay minerals. My own interests leaned toward mineralogy, so Clanton and I frequently met each other in the X-ray diffraction laboratory in the course of our separate research projects. At that time, the fields of planetology and space geology didn't exist. Clanton was soon the first geologist hired by the NASA Johnson Space Center. He would work on lunar hand tools, astronaut geology training, lunar image interpretation, high altitude micrometeorite collection and analysis, lunar sample analysis, and numerous other Apollo-related topics.

I had made up my mind to continue graduate study for a doctoral degree. The faculty at UT counseled me to select another graduate school for doctorate-level work; it was considered too inbred to earn three degrees from one school. After determining that my research interests were in mineralogy, my faculty advisors made a list of the schools they thought were in the forefront of mineralogical research and suggested I apply to the three or four that most appealed to me. I did as they recommended and requested letters of reference from my graduate school professors. They must have written very generous letters indeed, because I was accepted with a tuition scholarship at my first choice—Harvard.

May 1961 was a pivotal time in the course of the United States space program. Al Shepard took his gutsy suborbital ride on Mercury-Redstone 3 on May 5. Like so many others, I was glued to a television screen for the event. The United States had its first manned space mission—only 15 minutes and 22 seconds of actual flight—but it was a critical step.

John F. Kennedy's message to Congress in late May 1961, in which he stated his support for a manned mission to the moon, came while I was preparing to move to the Boston area. It was electrifying news! Would we really do it? In the following months, I carefully followed news items related to the "moon mission." Arguments about the terrestrial vs. lunar origin of tektites suddenly assumed greater importance, and the debate heated up. If tektites were lunar material, a number of important conclusions could be made about the origin and history of the moon and what kinds of rocks might be present on its surface. As far as I could tell, the arguments for a lunar origin of tektites were weak, but a lot of information was missing. I decided to try to work on some aspect of tektite research for my dissertation, but I was unsure about whether the geological sciences faculty at Harvard would accept a topic in this area. I would have to wait to find out about that. My first priorities were to get moved and settled (one wife, two daughters, a dog, and a cat). Our 1953 Plymouth and an unstable rented trailer hauled us to Boston. Meanwhile, Gus Grissom took a more elegant trip on Mercury-Redstone 4 on July 21.

My family and all our stuff were temporarily housed in a dingy little apartment in a poor section of Boston. After three weeks we found a more comfortable old two-family house that we could afford. The next order of business was to find Harvard. Armed with a street map, I set off in the car. The first time I drove right by the university without recognizing it. It looked nothing at all like the University of Texas. Classes would begin in a few days. I found the department and checked in with the departmental secretary, who ran her eyes over me with an experienced and appraising gaze, but gave me all the right information to get settled. I had only one

goal—to survive the first year!

The Geosciences Department at Harvard had a reputation among the students for being demanding. At the end of the first year, the faculty gave a critical review of each new student. They considered course grades and the general progress each student had made and determined whether each student could stay and work toward the Ph.D. If not, the student was asked to leave but was awarded a master's degree in recognition of having completed a year of course work. The percentage of students asked to leave at the end of the first year varied from year to year, but usually the number was high.

In the hall I met a tall, soft-spoken student named Gene Simmons, who said he was the only other Texan in the department. He showed me around and introduced me to the other graduate geology students. Simmons later joined the MIT faculty, became a principal investigator for lunar sample analysis, and served as chief scientist of the NASA Johnson Space Center.

The other graduate students were a really mixed bag. Some of them would finish in three years; others had been there for more than seven years. Some had completed every requirement for the Ph.D. except the foreign language reading exams. They seemed to have one thing in common—each of them knew a lot about something. I had a lot to learn from my fellow students as well as from the faculty.

During the course of introductions I met Jeff Warner, an extremely bright and active student with abundant nervous energy and a strong New York accent. Although we seemed an unlikely pair, we became very good friends. Warner later joined the faculty at the University of Alaska, then Franklin and Marshall College, and eventually went to the NASA Johnson Space Center as an expert in petrology and computer systems. He became a member of the Lunar Sample Preliminary Examination Team and a very active researcher with lunar samples as well as terrestrial geology.

In another office I was introduced to a student named Jack Schmitt from New Mexico. Schmitt handed me a rock and asked me

to identify it. It was a high-pressure, high-temperature rock called eclogite, composed chiefly of the pyroxene mineral omphacite and garnet. I identified it correctly. Schmitt was impressed and surmised that probably I would be a successful Harvard graduate student. Schmitt was doing his dissertation on Fennoscandian eclogites and had an inflated opinion of their importance. Schmitt later went to work for the U.S. Geological Survey (USGS) and was selected as a NASA scientist-astronaut. He reached the Moon as a member of the Apollo 17 crew, the only geologist to do so. After the Apollo program, Schmitt was elected to the U.S. Senate from New Mexico.

Things went well. Only one course caused me any problems during the first semester, and I completed the reading exams in French and Russian. The Harvard mineral collection was fantastically beautiful and complete. The department also had a magnificent collection of meteorites. I was eager to get started on dissertation research, so I decided to approach my faculty advisor, Dr. Cornelius S. Hurlbut, Jr., about working with tektites. Hurlbut had been on the Harvard faculty for many years and had a worldwide research reputation. He was a sensitive, friendly man who was genuinely interested in helping students, particularly if they were interested in mineralogy. He thought about the topic for a minute, remarked that none of the faculty was particularly knowledgable about tektites, but suggested I summarize the tektite literature and bring him a written proposal in the next few months.

Dr. Clifford Frondel was another well-respected member of the Harvard faculty and whose presence there was one strong reason I chose Harvard for further graduate study. Frondel later became a member of the Lunar Sample Preliminary Examination Team for the early Apollo missions and a principal investigator for the mineralogy and petrology of lunar samples.

Though not the best formal lecturer I had ever known, Frondel's mind was stuffed with an incomparable accumulation of mineralogical knowledge. He was at his best in small seminars and classes that he held at his home, over cookies and hot coffee provided by his wife, Judy, also an accomplished mineralogist, who later com-

piled a volume on the mineralogy of lunar rocks.[4] Typically, Frondel's class presentations provided a thorough historical background for each topic, summarized what was known about the topic, and carefully pointed out what was not known about each topic. He frequently passed fabulous specimens among the students to illustrate his points.

I prepared the proposal on tektites that Hurlbut had requested and turned it in to him. Several days later he called me into his office and said the proposal looked fine and I could start on the work whenever I had time. He also suggested I talk with Dr. Bill Pinson, a member of the MIT faculty, who had a student working with him on tektites. I didn't find Pinson on my first trip to MIT, but I met his student, Charlie Schnetzler, with whom I exchanged some ideas and conversation. He was working with the geochemistry of tektites, strontium-rubidium mass spectrometry in particular, which was unrelated to what I wanted to do. Also, he leaned strongly toward a lunar origin for tektites (as did Pinson), so we interpreted many facts quite differently. He was an amiable young man. I enjoyed talking to him, but we had little further contact. Schnetzler later joined NASA at the Goddard Space Flight Center and provided some of the most convincing support for the terrestrial origin of tektites prior to the actual return of lunar samples.

During the fall, a local Boston television station wanted to air a debate on the lunar vs. terrestrial origin of tektites. Pinson was chosen to argue the lunar side, and the station wanted to recruit someone to argue the terrestrial side. They contacted me about doing so. After briefly thinking it over, I declined. If I lost the debate, I might come off looking bad, maybe even stupid. If I won the debate, I might make Pinson look bad. I didn't want to risk making any enemies on the MIT faculty. It clearly was the safest decision for a new student in the Boston area.

The first semester was over. Christmas and the New Year's celebration had come and gone. The Boston winter was in full swing

[4]J. W. Frondel, *Lunar Mineralogy* (New York: Wiley-Interscience, 1975).

with snow, subzero temperatures, and brisk wind. In February 1962, John Glenn led the American way into low Earth orbit. I was hanging on every picture, event, and word from the flight. My heart still has a warm spot for Australians simply because the City of Perth turned on its lights for Glenn. We may have been lagging behind the Russians, but for me, the orbital flights of John Glenn, Scott Carpenter, Wally Schirra, and Gordon Cooper were inspirational, and I was confident we would catch up. Project Mercury flights ended with Cooper's splashdown on May 16, 1963. It was nearly two years before the first Project Gemini flight. At the time I never dreamed I would not only get to meet the Mercury astronauts but would have the opportunity to work with them as well.

One morning when I came to the department, I noticed several students looking at the ceiling above one graduate student's desk. They were looking at what was purported to be a geologic map of a portion of the surface of the Moon.[5] They had tacked it to the ceiling to depict the normal orientation of the lunar surface to earthbound observers. It was not a complicated map, but using photogeology, the author had interpreted the major time-stratigraphic relationships of a part of the surface of the Moon in a way that looked very convincing. The map stayed on the ceiling for several weeks and provoked a lot of thought and discussion.

I wanted very much to get involved with NASA programs, particularly with the exploration of the Moon, but I didn't know how to go about it. Besides, I still had classes to worry about, and I was going to take my oral exams in a few months. The exams were absolutely critical. I had to take one step at a time, and I planned to get my oral exams out of the way. Then I could finish the research and writing of my dissertation during the next academic year, 1963–64. In the early spring of 1963, I decided it was time to start looking for a postgraduate job, preferably in a space-related geology field. Dr. Eugene Shoemaker had emerged as the public spokesman for

[5]R. J. Hackman, Geologic map of the Kepler region of the moon, U.S. Geological Survey, Misc. Geol. Inv., Map I-355 (1962).

space-related geology, particularly for the lunar program. Although I had never met him, I had listened to him present technical papers. I knew he was an enthusiastic and influential player in the game. Also, because he was setting up a new organization in Flagstaff, he might have some jobs available in a year or so. Shoemaker had earned his Ph.D. from Princeton University, where he had worked on the impact mechanics of Meteor Crater, Arizona. He had joined the U.S. Geological Survey and served as a consultant to NASA headquarters in Washington, D.C. Shoemaker became the principal investigator for the Lunar Field Geology Experiment for the early Apollo missions and later joined the Cal Tech faculty.

I carefully drafted a letter to Shoemaker and prepared a professional résumé to accompany the letter. The résumé was brief, but I had a few publications to my credit and tried to make the best of it. This could be an important letter for me, so I sweated considerably over the organization and exact wording. I still did not have a draft with which I was entirely happy when I came home and found a note to call Uel Clanton in Houston—IMPORTANT!

I returned Clanton's call and asked what he was doing in Houston. I thought he was still in Austin working on his dissertation. He had taken a job with the NASA Johnson Space Center (or Manned Spacecraft Center, as it was then known) and was helping develop instruments and tools for use in space, training astronauts in geology, defining the lunar surface environment, etc. He was right at the heart of the action! He was calling me because there was a job available at NASA in his organizational element (which became the Lunar Surface Technology Section). His NASA bosses wanted a geologist who knew a lot about the lunar surface. I didn't know anything about the lunar surface! Clanton told me that I must know about the lunar surface because I knew about tektites, and there was a prominent senior NASA scientist at the Goddard Space Flight Center who had convinced almost everyone at NASA that tektites came from the Moon. The NASA scientist was, of course, John O'Keefe, whose work with tektites was familiar to me. I told Clanton I did not share O'Keefe's view of tektites, but he said it really

didn't matter. There would be lots of other tasks for me to do, and I could keep track of tektites on the side. Clanton was sending application forms. He told me I could think it over for a couple of days, but his section wanted to move quickly to avoid losing the position.

I sought the advice of my professors. Initially, Hurlbut was lukewarm. NASA was an engineering management organization, not famous for in-house scientific research, although the lunar program was unique and might develop into something. However, the job might delay the completion of my dissertation and degree, and Hurlbut advised me to make my decision carefully. Frondel, on the other hand, was immediately enthusiastic. He shared Hurlbut's concern about the delay in obtaining my Ph.D. but thought this might be an interesting opportunity for me. He believed the samples brought from the Moon would be a "magnet that would draw scientists from all over the world."

My own thoughts about the job were positive. After watching all those NASA launches and following the Mercury missions, NASA clearly seemed the place to be. They were really doing things—things of national importance and historical significance. I filled out the application forms and requested an employment date at the end of the summer so I could finish my dissertation field work in Georgia and Texas. Completion of my field work would leave me only a minor amount of laboratory work to complete for my dissertation. The rest was writing. NASA agreed, and some weeks later I received a formal letter offering me a position. I immediately accepted. I was slowly but certainly on my way to the Houston space center and the Apollo program.

I. The Space Center

The Manned Spacecraft Center (MSC) did not yet exist as a physical entity. Center personnel and organizations were spread out in more than a dozen locations, mostly on the south side of Houston. Headquarters was located in the Farnsworth-Chambers Building, an old construction company office building that appeared to have been inspired by Frank Lloyd Wright's "organic" period. My unit was located in old, remodeled barracks at Ellington Air Force Base, which had been a pilot training facility about the time of World War I.

It was mid-August when I arrived, and the miserable Houston summer was totally oppressive. Austin could be hot, but the typical Houston summer climate is hot and humid, with about the same temperature and humidity statistics as Calcutta. For many years the British Consulate personnel working in Houston drew hardship

pay because of the climate, an unpopular fact with the Houston Chamber of Commerce. To make matters worse, my ancient car was not air-conditioned.

With the help of an Air Force security guard, I found the building that housed my new boss' office. I became completely soaked in sweat just walking from the parking lot to the building. On the way in I spotted Clanton at a desk. After a brief reunion, he took me in to meet my new boss. After 40 minutes of conversation, I went away completely discouraged. I soon met and chatted with some of the other chiefs and administrative personnel and became depressed for a couple of months. No one in authority in this part of NASA appeared to have any real concept of science or its progression. Most of the lower- to middle-level managers and administrators were extremely insecure and spent most of their time trying to understand or affect internal politics. I assumed that somewhere in the hierarchy above the managers I had met worked a group of very bright and capable managers and scientists because, after all, NASA worked! From my local vantage point, however, it was clear I would be fighting an uphill battle to include much consideration of scientific matters in my organization's work. I was working in a purely engineering-oriented environment where directives from above were rarely questioned—hardly the kind of group I was accustomed to.

I was further perturbed by the dress code. Even the lowest bureaucrat wore a coat and tie on the hottest day. I was used to the comfortable old shirt, worn sweater, and slacks or jeans of my graduate student days. At NASA, however, status was based on wearing a jacket and tie. Many of my NASA colleagues dressed in checkered or plaid jackets worn with checkered or plaid pants, a white or blue shirt, or even strawberry slacks with a white belt and shoes. I felt like I was surrounded by a band of California golf pros.

In addition, I slowly realized that I had been hired into a three-way political battle between MSC, the USGS, and NASA headquarters. The USGS wanted to handle all of the geologic support for the lunar program, and some parts of NASA headquarters had agreed

to this, in concept. While this agreement was negotiated, however, MSC hired its own geological staff. We were in the middle of a power struggle between MSC and NASA headquarters in addition to being embroiled in inter-agency politics. A working agreement was reached whereby the USGS and MSC would each furnish about the same number of geoscientists. We were glad to have some additional scientists around. We got along well at the working level, but our superiors spent a lot of time working on their ulcers.

My first order of business was to learn about the Moon. As I suspected, there was not a great deal known about the Moon, particularly the geology and topography of the surface. Few astronomers had continued interest in the Moon. Most went on to "more sophisticated topics," and the Moon had been left to the attention of only a few professionals such as A. Dollfus, E. Whitaker, E. Opik, Z. Kopal, and G. Kuiper. Clanton suggested a book by Baldwin[6] as a good place to start. It was a recent, up-to-date work by a man originally trained as an astronomer but whose work had earned professional recognition in geosciences and planetology. I quickly finished this and several other volumes. A few weeks of critical reading took me as far as I could go.

A large amount of the literature current at the time was devoted to arguments over the origin of lunar craters. Through the years the debate narrowed to volcanic versus impact origins. The side for impact origin of lunar craters was represented by Shoemaker, and the volcanic origin side was capably argued by Dr. Jack Green, a geologist who worked for an aerospace contractor. This was an important argument as far as the Apollo program was concerned because the different crater origins would produce different rock types and small-scale morphology of the lunar surface. It appeared to almost everyone that the impact origin side had better grounds, which were strengthened by the recent recognition of several large terrestrial impact craters.

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[6]R. Baldwin, *The Measure of the Moon* (Chicago: University of Chicago Press, 1963).

Another argument about the nature of the lunar surface was put forth very aggressively by T. Gold of Cornell University. He theorized that fine lunar dust was transported to lower areas of the Moon by electrostatic processes and that this could lead to dust accumulations more than a kilometer thick. These fine dust accumulations would have little strength to support objects on the surface and might prove to be serious hazards for astronauts and spacecraft. NASA was quite concerned about this hypothesis, as you might imagine! It was a difficult idea to refute, and Gold was very outspoken about it. We needed a way to deal with this idea and either prove or disprove it. The final answer came from the several unmanned spacecraft, both Soviet and American, that successfully landed on the Moon.

I asked around about what plans had been made for the receipt, proper handling, and examination of the lunar samples collected by the Apollo missions. As it turned out, this subject had received almost no serious thought, just a few disjointed ideas. Here was a scientific topic MSC could not ignore. I could really sink my teeth into this one. I talked to my boss about the topic, informing him that a facility would have to be provided to protect the samples and to gain enough scientific information to distribute them to the most qualified specialists for detailed investigations. After some discussion, my boss told me to prepare a draft memorandum on the matter. This topic was fairly broad, and I requested some technical help. The boss said that I could work with Don Flory, a chemist. After weeks of discussion, Flory and I drafted a lengthy memo pointing out the need for a carefully designed facility to receive and protect the lunar samples. We addressed the memorandum to the directorate level. This made our boss uneasy, but it was the only level at which anything significant could be achieved. The boss agonized over our draft for nearly four weeks. He didn't want anything too controversial to originate from his section. He called Flory and me into his office several times. He talked to us together and separately. Finally, he accepted the memo and instructed the secretary to type the memo in final form. Then he signed it and sent it out. The con-

figuration and content of the lunar sample facility took on many forms as it proceeded through different advisory committees and consultants before it was finally constructed, but this was the beginning of the Lunar Receiving Laboratory.[7]

The NASA geologists were quite concerned that none of the astronauts had any training in geology. This concern was shared by the scientific community, who wanted scientists included on lunar landing missions. Since the astronauts would be landing on some sort of "rock pile," it seemed appropriate for them to know something about rocks. The concept of a geology training course for the astronauts was quickly accepted, and we were told to prepare a detailed course outline. This would be a joint USGS and MSC staff activity. The MSC group was led by Ted Foss, a soon-to-be Ph.D. from Rice University who joined NASA at about the same time I did. The USGS group was directed by Dr. Dale Jackson (later Dr. Al Chidester), an experienced field geologist. Both groups worked together to compile a series of classroom lectures and geological field trips and exercises to provide the flight crews with general background as well as specialized information about the lunar surface. The Astronaut Office bought the whole package with minor modifications. It was clear we would be spending quite a bit of time training astronauts in geology, but we looked forward to it. After all, these were the guys who would land on the Moon.

Another function that fell our way was monitoring contracts for the design and development of various pieces of space hardware. This was principally an engineering task, one for which I felt totally unprepared. We spread the work around as equitably as possible, and I drew the development of a drill to be used on the lunar surface. I knew nothing about rock drilling, but at least I knew something about rocks. The prime contractor for the drill was located in Baltimore, Maryland, and the supervisor of the project for the contractor was a young engineer named Don Crouch. Crouch later be-

[7]J. C. McLane, Jr., E. A. King, Jr., D. A. Flory, K. A. Richardson, J. P. Dawson, W. W. Kemmerer, and B. C. Wooley, "The Lunar Receiving Laboratory," *Science*, vol. 155 (1967): 525–529.

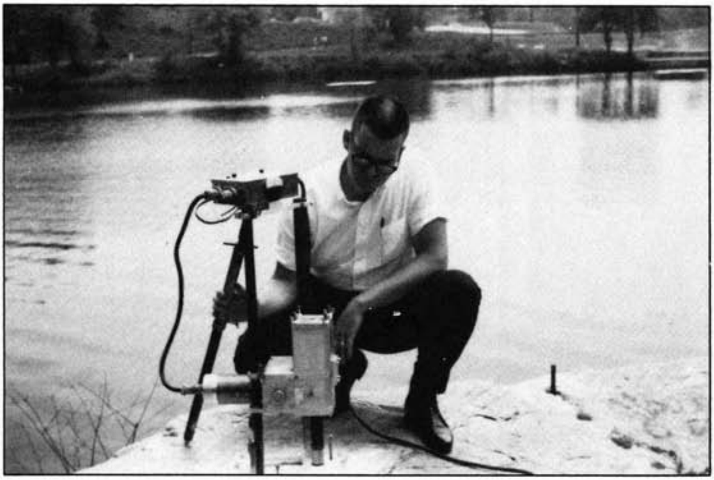

Photo 3. The author with a test rig for components of an early prototype of the lunar surface drill, in an abandoned rock quarry near Baltimore, Maryland. (Photograph by the author)

came the engineer responsible for the design of the sampling arm on the two Viking spacecraft that landed on Mars.

The drill would be used to provide subsurface samples and to drill holes for placing instruments in the lunar surface. Drilling a hole in the lunar surface would be different from standard rock drilling on the Earth, mainly because we would not be able to use water as a drilling fluid to wash cuttings out of the hole and cool the bit.

After reviewing the literature on rock drilling and making a few engineering tests, we decided a rotary-percussive system with a core bit looked most promising and set about fabricating some components and test models (Photo 3). We tested the drill components in the lab and in an abandoned rock quarry in Baltimore. During one of those trips to Baltimore for drill tests, Crouch asked me what I wanted for lunch. Without hesitation I said, "Seafood." We drove to a little roadside cafe where I was introduced to Maryland soft-shelled crab. I wasn't exactly sure what I was ordering, but Crouch strongly recommended the soft-shelled crab sandwich.

When the sandwich arrived it looked grotesque. It was a whole crab with a piece of bread on each side and legs and claws sticking out everywhere, but I had to admit it was very tasty.

I was eventually relieved as technical monitor of the lunar drill contract, which I appreciated, but my experience with drilling led to an invitation to go to the Marshall Spaceflight Center in Huntsville, Alabama, to participate in a source evaluation board for a deep lunar drill. Marshall was the NASA center responsible for rocket development. During the course of a three-day board meeting I was invited to a cocktail buffet at a high-ranking manager's home. I arrived a few minutes late because the hand-drawn map I was following was incorrect. The party already had a glow, and I heard the dull roar of 50 simultaneous conversations as I walked up the driveway. I found a drink, recognized several of the other evaluation board members, and was taken in tow by my host, who introduced me around. To my surprise most of the old German "rocket mafia" were there—Wernher von Braun, Ernst Stuhlinger, and a host of others. I had never expected to see them. These were some of the same scientists and engineers who had developed the rockets that terrorized London in World War II. As the party wound down and thinned out, the Germans settled into a sofa-and-chair arrangement in the center of the main room. There was much talk of the Saturn "Moon rocket." The development and testing of the Saturn was going well. Although they had many concerns, these Germans were confident it would work. Their conversation was strictly in English, even their occasional reminiscence about "the old days" and sailing on the lakes in Berlin. I drove back to my motel pondering the curious chain of events that had placed me here in space and time. Perhaps the Germans had similar reflections.

Our section got a telephone call from the trajectory analysis group. They wanted to run some sample spacecraft trajectory calculations for the Moon and needed some coordinates for probable landing sites. We didn't have any, but the boss said we had better get some. Various engineering and mission requirements limited the early landing sites to a "bow-tie"–shaped area centered on the

visible face at the lunar equator (Figure 1). In collaboration with the USGS geologists, we arranged for time on some large telescopes to look for smooth places in the "bow-tie." The resolution of even the largest telescopes at best "seeing" conditions was insufficient for selecting landing sites, but we tried to locate the areas that appeared smooth. Our first attempt to view the Moon was at the Kitt Peak Observatory near Tucson, where a large solar telescope was immediately available because solar observations were not made at night. Four of us flew to Tucson and tried to get some afternoon and early evening sleep. After dark we drove up the mountains to the observatory. The solar telescope was a massive structure with a huge mirror that could be moved to track the Sun or the Moon. The image was reflected to another mirror underground and finally projected on a table-like surface in the observing room. The observing room and tunnel leading to it were dimly illuminated with dark orange-red lights to protect night vision. The slew motor on the mirror made a plaintive, high-pitched whine, dark shadows darted across the cold orange-red walls, and in the center of the room a group of men huddled over an image of the Moon, using small viewers to magnify desired areas. It looked and sounded like the setting for some fantastic tale of science fiction. We outlined the areas that appeared dark and smooth.

We also booked some time on the big refracting telescope at the Lowell Observatory near Flagstaff. The observatory was founded in 1894 by Percival Lowell, a wealthy Bostonian who developed an interest in planetary astronomy, especially in Mars. Lowell used the observatory to map and document "canals" and other features of the martian surface. He generated great public interest in his work because of his conviction that the canals were produced by "intelligent creatures." Although the telescope was a very old instrument, it was optically quite good, having been produced with enviable attention to quality and detail. We spent two nights at the instrument and were fortunate to have one evening of very fine "seeing." We confirmed our previous observations of the relative smoothness of some dark areas in the bow-tie and provided the coordinates of

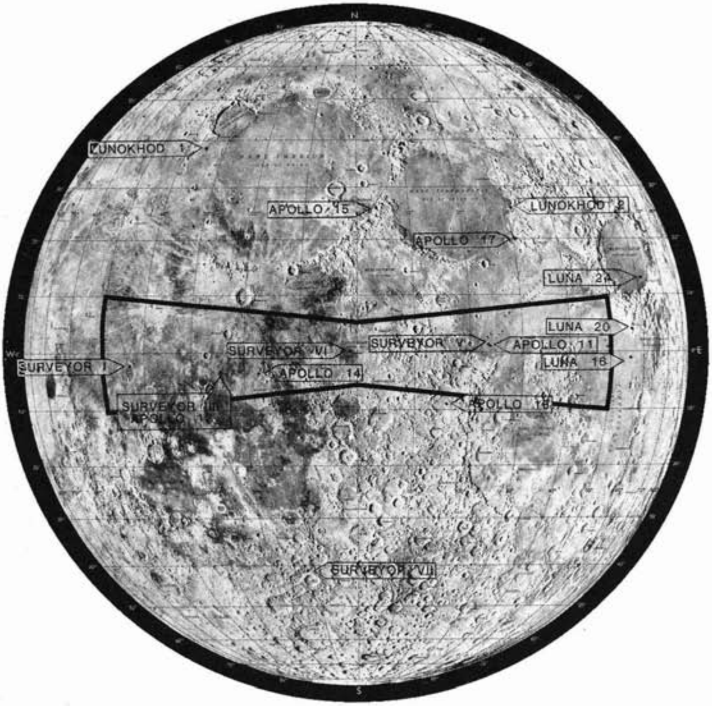

Figure 1. Lunar nearside chart showing soft landing sites for both American and Russian spacecraft as well as "bow-tie"-shaped zone to which early Apollo missions were restricted by free return trajectory and communications constraints. (Adapted from U.S. Air Force and Lunar and Planetary Institute charts)

the centers of the two best-looking areas to the trajectory analysis group so it could begin serious work.

No matter whatever else we had to do, I tried to maintain an active program of tektite research. Also, I was beginning to work with meteorites. Several researchers had suggested different meteorite types as possible lunar material. Some lunar rocks could be accelerated to velocities sufficient to escape the Moon by the impact of meteorites on the lunar surface. Most of this lunar debris would fall on the Earth as meteorites. Somewhere among the collections of

meteorites there should be pieces of the Moon. The challenge was to recognize them. Unfortunately, this would not happen until well after the Apollo program.

The low point of those first months was the assassination of President Kennedy. Everyone was stunned. Regardless of our political views, we all felt a particular fondness for Kennedy because he had given NASA the goal it needed. Without his bold political decision, the whole affair might never have happened.

Around the end of February 1964, various elements of the space center began moving to the permanent site. Only a few years before, the site had been a large, flat, grassy cow pasture between the towns of Webster and Seabrook. Although located on what is locally considered "high ground," the site was not far above mean sea level, as indicated by the shore of Clear Lake, which bordered the site to the east. As part of the land acquisition agreement, NASA allowed retention of a large potential oil well drilling site near the center of the property. Nonetheless, construction proceeded rapidly, and the move to the space center was welcomed by almost everyone, especially because the new buildings and facilities were much more comfortable and functional. Our group was one of the last to leave Ellington.

II. Astronaut Geology Training

We began the geology training course with 29 astronauts. John Glenn attended some of the early classes, but was not formally included since he had other obligations and was not expected to fly in the Apollo program. We began with lectures by a variety of instructors. The topics were introductory physical geology, mineralogy, petrology, and the Moon. These were presented mostly by the MSC staff and the USGS geologists. The quality of the lectures was uneven—some were good, some were awful. Some of the class members complained about a few of the instructors, and the list of lecturers was revised accordingly. The astronauts were very busy people. They had many other training courses and things to do besides study geology. We could not afford to waste their time with poorly prepared or badly presented material—this was made abundantly clear. Furthermore, the crew were not really very interested

in general background; they wanted to get the information they needed for observing and collecting rocks on the lunar surface. My first lecture was delivered in February 1964. I had to cover everything they needed to know about mineralogy in a one-hour lecture. This was a tall order. I got through the material, leaving a lot of gaps out of necessity, but the astronauts seemed satisfied. I kept the roll sheet from this first class as a souvenir.

A wide range of academic ability, background, and interest existed among the group. Although we continued to lecture from time to time, we found that intensive instruction on field trips was more productive. Each instructor was assigned two or three astronauts as his students for each field trip or field exercise. That way the astronauts were not as shy about asking questions, and the instructor got to know the strengths and weaknesses of each one. We commonly made three field trips out of one. That is, all the geologist instructors, including an expert on the local area, took one trip to outline the work and compile the program. Then, usually two trips were taken with different groups of astronauts because all of them could not get together simultaneously. As crew members were named for the Gemini Program flights, we commonly lost students until after their flights. With five Gemini flights in 1965 and another five in 1966, each with a two-man crew, we were challenged to provide continuity in the instruction, but we did the best we could.

We chose a set of field trip sites where there would normally be two to three days of instruction. We started with basic sites and progressed to more complicated areas and exercises. For our first field trip we selected Grand Canyon. Although this area bears no resemblance to the moon, it provides an excellent "classroom" for teaching elementary principles of stratigraphy, geologic mapping, and air photo skills. In addition, the Grand Canyon is such a scenic place that we hoped to get even the most reluctant astronaut students "hooked" on the charisma of geology and field work. Also, we could count on the help and cooperation of the Park Service in a national park.

We were pressed for time to get the canyon field trip organized.

We flew to Flagstaff and drove to the south rim. We had only one day in the canyon to plan the exercises. This meant we had to hike down and back out on the same day. We made it, but by the time we changed airplanes in Phoenix, we were hobbling around with muscle pains, leg cramps, and blisters. We could only laugh at what we must have looked like.

The astronauts' better physical condition annoyed the geologists throughout the geology training course. Some of the instructors started running and exercising regularly, but it always seemed the astronauts were far ahead of us. It was particularly difficult to go from sea level in Houston to field trip localities at higher elevations. In the end, it was just a fact of life we had to accept.

Near the end of March 1964, the astronauts went on the canyon field trip, arriving with a NASA-MSC public affairs officer, Paul Haney, and a couple of NASA photographers. Several local news media representatives also were present. Everywhere we took the astronauts, the local press had to be accommodated with information, photographs, and press conferences—a continuing problem for the field trip instructors.

We hiked down the Kaibab Trail from the south rim and returned by hiking up the Bright Angel Trail to Indian Gardens, where we rode mules the rest of the way out. Mike Collins and Roger Chaffee were my students for this exercise (Photo 4).[8] They were willing students who had no trouble grasping the concepts we wanted them to understand. The weather was beautiful, as was the canyon. For the geologists and astronauts it was an enjoyable experience, and there was quite a bit of good-natured horsing around (Photo 5). The field work started on good footing. As we reached Indian Gardens on the way out, some of the astronauts decided to continue hiking and refused to ride mules. This small but determined group was led by Al Shepard.

Feedback from the first field trip was positive. The astronauts

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[8]For additional information and a more comprehensive view of the astronaut training program, see R. R. Gilruth, "The Making of an Astronaut," *National Geographic*, vol. 127, no. 1 (1965): 122–144.

Photo 4. Astronauts Mike Collins (left) and Roger Chaffee (right) at the "Great Unconformity" in the inner gorge of Grand Canyon. Thinly bedded Paleozoic sedimentary rocks unconformably overlie much older igneous and metamorphic rocks that are deeply weathered. (Photograph by the author)

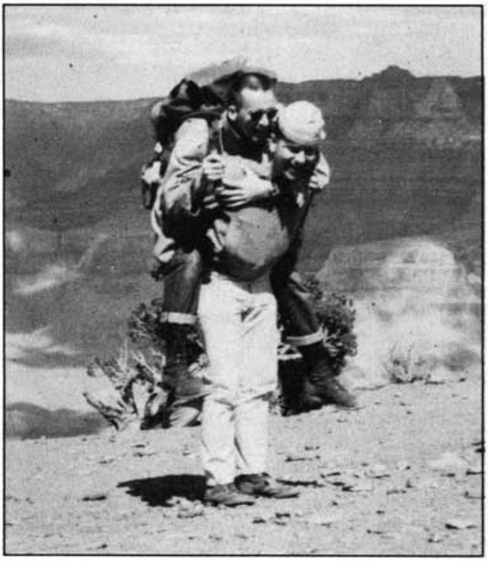


Photo 5. Astronaut Walt Cunningham trying to use NASA Public Affairs Officer Paul Haney (with hat) as a "mule" for his descent into Grand Canyon. (Photograph by the author)

much preferred this form of instruction to formal lectures and classes. The geologist instructors agreed that a lot of teaching and learning had been accomplished in the field with relative ease.

In April, we held another field trip to the Marathon Basin and Big Bend of Texas, with Muehlburger as the local expert. The weather was already warm and sunny in far West Texas. There, we continued to emphasize stratigraphy, but also taught some structural geology and introduced volcanic rocks (Photo 6). Like the Grand Canyon, Big Bend is a beautifully wild place, particularly in the springtime before the full heat of summer arrives (Photo 7). On the preliminary trip to Big Bend, I began to feel ill. I was having difficulty concentrating and was suffering

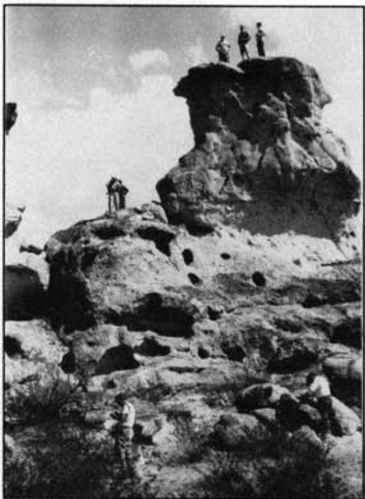


Photo 6. Field party of astronauts and geologist instructors examining an outcrop of ash-flow tuff near Three Dike Hill west of Big Bend National Park. (Photograph by the author)

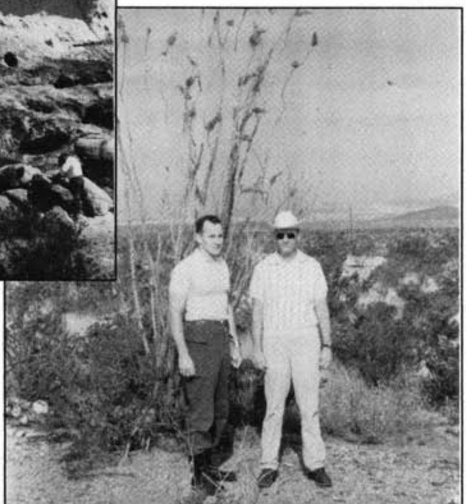


Photo 7. Astronauts Ed White (left) and Tom Stafford (right) along the highway in the low desert of Big Bend National Park. (Photograph by the author)

from dizziness. When we arrived in Terlingua, an old ghost town that was once a mercury mining center, I drank a couple of cold beers, but they didn't help at all. I was eager for the day to end. It finally ended in Alpine, where I visited a local doctor who diagnosed my illness as mumps, which I never had as a child. This was not a popular diagnosis, since several of the geologists didn't remember ever having mumps. The group lined up for gamma globulin shots as a preventive measure! I was fortunate to experience no complications and was back in action in plenty of time for the trip with the astronauts.

Most of the NASA group arrived in one of the NASA aircraft at Marfa, Texas (Photo 8), where we had to make a low pass over the runway to frighten away the antelope before landing. We proceeded via rented cars to the field trip areas. The rental cars were standard four-door sedans, not well-suited for the unimproved roads, and were returned to the rental agency looking quite a bit worse than when we picked them up. The rental car agent was unconcerned. He simply said in a long, west-Texas drawl that he was "proud to be helpful to NASA."

Photo 8. NASA passenger aircraft on the runway at Marfa, Texas. Surrounding the Grumman Gulfstream are astronauts, geologists, onlookers, and rental cars. (Photograph by the author)

Photo 9. Local observers (right) watch geologists and astronauts making a "booze run" in a Mexican border town. Astronaut Scott Carpenter is seated on car fender at left, having already made his purchase. (Photograph by the author)

There were many lessons to learn in Big Bend. One was discovered by Neil Armstrong, who hit a basalt outcrop with his rock hammer and was cut slightly on the arm by a flying rock chip. This was not the correct way to collect rock samples, either on the Earth or the Moon. Even a small cut in a space suit could have serious consequences. Wally Schirra spent a lot of time with his Haselblad "documenting" samples he collected or photographing important rock outcrops. In the cool evening, we enjoyed a few beers, a good Tex-Mex dinner, and a couple of poker games. On our way back to Marfa to board the NASA aircraft, a number of us crossed the Rio Grande into Mexico to make a "booze run" (Photo 9), taking advantage of duty-free, low Mexican prices.

About mid-year we arranged a trip to the Philmont Ranch in New Mexico, another scenic locality with good local logistical support. Jeeps were reserved from a military motor pool, there were comfortable cabins where we could stay, and breakfast and dinner were served in the cafeteria. The ranch was operated as a retreat

and summer camp for Boy Scouts. The Philmont personnel were accustomed to catering to large groups, so our party would not strain their facilities. They were genuinely anxious to accommodate us in any way they could.

I was unable to arrive at Philmont with the rest of the group, due to a committee meeting I had to attend at the Jet Propulsion Laboratory, so I flew from Los Angeles to Albuquerque and drove to Philmont in a rented car. I had asked for the standard government-rate vehicle, but the agency was almost out of cars. They agreed to let me have a new Chevy Malibu super sport convertible for the same price. It was early evening of a clear cool night. On the radio I found Eugene Ormandy and the Philadelphia orchestra just beginning to play Scheherazade. With the top down and little traffic north of Santa Fe, the drive was memorable. Around one curve in the mountains I suddenly came face-to-face with eight deer crossing the highway. I braked and dodged—so did some of the deer. The others leaped straight up into the air. Somehow we missed each other, but I drove on at a considerably slower speed.

The geology at Philmont was pretty simple with excellent exposures of igneous and sedimentary rock types. The astronauts oriented themselves on geologic maps (Photo 10), measured and described stratigraphic sections (Photos 11–12), took strike-and-dip measurements, and recorded lots of field notes under close supervision (Photo 13). I spent most of my time working with Ed White, Jim Lovell, Roger Chaffee, and Al Bean, who were all good students.

Bean had heard tall stories from the locals about gold in the immediate area, and he wanted to try to pan. We didn't have any gold pans, but Bean improvised with an automobile wheel cover and an aluminum pie pan. Bean asked me to pick a place where I thought, as a geologist, that he could find gold. I told him that if I knew how to do that I would be cooling my heels on the French Riviera, rather than wandering around in the New Mexico woods. Undaunted, Bean found a place where he could pan without getting too wet (Photo 14). He was jubilant when he found some gold-col-

Photo 10. Geologists Dale Jackson (left) and Uel Clanton (light western hat) explain geological map to astronauts (left to right) Al Bean, Neil Armstrong, Bill Anders, and Roger Chaffee at the Philmont Ranch in northern New Mexico. (NASA photograph S-64-23876)

Photo 11. Astronaut Al Bean resting with his Jacob's staff at the top of a stratigraphic section that he has just measured and described near the Philmont Ranch in northern New Mexico. (Photograph by the author)

Photo 12. Astronauts Roger Chaffee (left) and Dave Scott look over the way to the top of a stratigraphic section they are measuring and describing as a field exercise near the Philmont Ranch in northern New Mexico. (Photograph by the author)

Photo 13. Astronaut Jim Lovell (left) taking a strike-and-dip measurement while the author observes. (NASA photograph S-64-23849)

Photo 14. Astronaut Al Bean attempting to pan for gold along a small creek near Philmont Ranch in northern New Mexico. (Photograph by the author)

ored flakes in his pie pan, but quickly came back to Earth when I identified his "gold" as weathered biotite, a black mica mineral that can weather to a soft yellow color but is much more brittle and much less dense than gold. During conversation at the side of the stream while "prospecting" for gold, Bean and I discovered that we had both gone through Navy ROTC at the University of Texas. Bean had been in the class two years ahead of me, but for some reason we never met during our two years of overlap at UT.

The lighthearted moments at Philmont were special. White dared the other jeeps to a race back down the mountain at the end of the day. He started off, and the challenge was quickly taken up by the other jeeps loaded with astronauts and geologists. This was not the most prudent activity for a narrow mountain road, especially with the lead jeep stopping quickly from time to time to roll a boulder or drag a dead tree into the road.

During one field exercise, Lovell suddenly pretended to be overcome with emotion over geology and the great outdoors. He placed a mountain lily behind his ear, clasped his rock hammer to his breast, and managed a most noble expression (Photo 15).

At the end of one day, we stopped at a little beer joint in Cimarron. We were tired and dehydrated, and a couple of beers caught up with us in a hurry. Pete Conrad started telling jokes and kept the group completely entertained for 40 minutes. We especially liked his pilot jokes, but he soon started telling geologist jokes adapted from Texas "aggie" jokes. He was hilarious. Conrad could always work as a stand-up comic if he decided to give up the astronaut business.

Another day we stopped at a private museum dedicated to Kit Carson. Armstrong and I had plenty of time, so we decided to see the exhibits. They were interesting enough, but the real find was an old airplane tucked away in a corner of an old building. The plane had a wooden frame, and most of the canvas was rotted off so all the control cables and other guts of the machine were visible. Inside was a tiny internal combustion engine that looked barely capable of turning the prop. Armstrong was fascinated. It was a strange con-

trast to see a former X-15 rocket pilot admiring an antique open-cockpit, stick-and-rudder craft. He clearly liked flying machines.

When the Philmont trip was over, I had to drive back to Albuquerque to turn in my rental car. It also happened that Mike Collins needed a ride to Albuquerque. He had flown a jet to the Air Force base in Albuquerque on the way out, and his ride back to

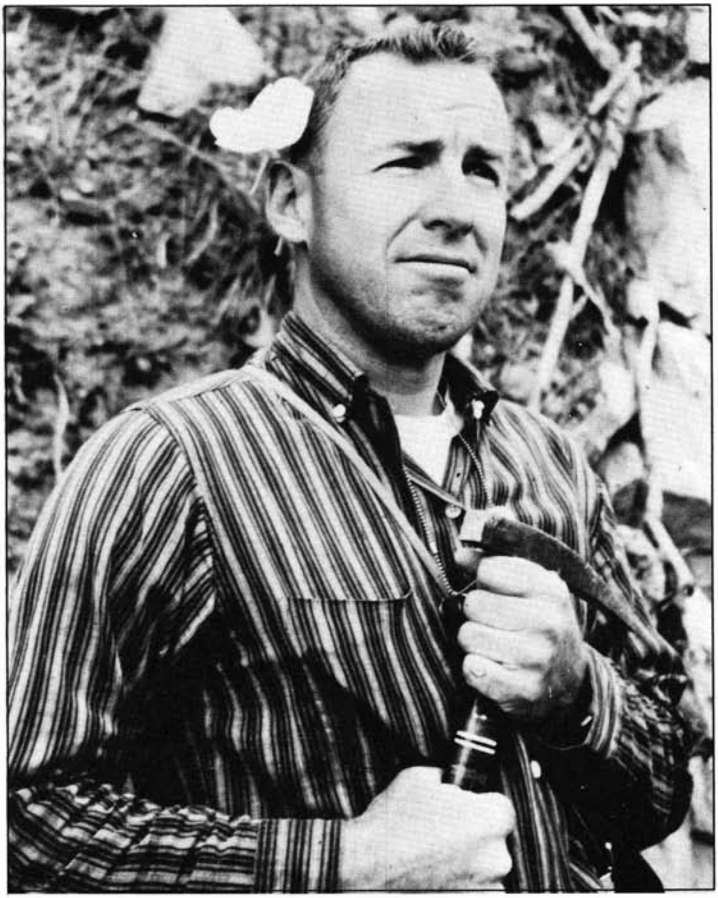


Photo 15. Astronaut Jim Lovell mugging for the camera in an "inspired" moment during a field exercise at Philmont Ranch in northern New Mexico. Note geologist's pick, hand lens on chain around neck, and flower. (Photograph by the author)

Albuquerque had to leave the trip early. We arrived at the Air Force base where I delivered Collins to his plane. I asked him some questions about airplanes, and he offered to show me a few things while he did his ground and cockpit checks. He performed a thorough check and then took off. I had never realized how simple small jet aircraft are. They are such elegant little craft, and it is easy for me to understand why some aeronautical engineers and pilots are so enthusiastic about them.

Field trips followed to the Bend, Oregon, area (Photos 16–19) and to Valle Grande, near Los Alamos, New Mexico, to study different types of volcanic rocks. Both were excellent study areas, but working in the Valle Grande region was especially strenuous physically. Astronaut Ted Freeman (Photo 20) sprained his ankle badly. A short time later, on October 31, 1964, Freeman was killed in a flight accident near Ellington Air Force Base when his plane collided with a flock of geese.

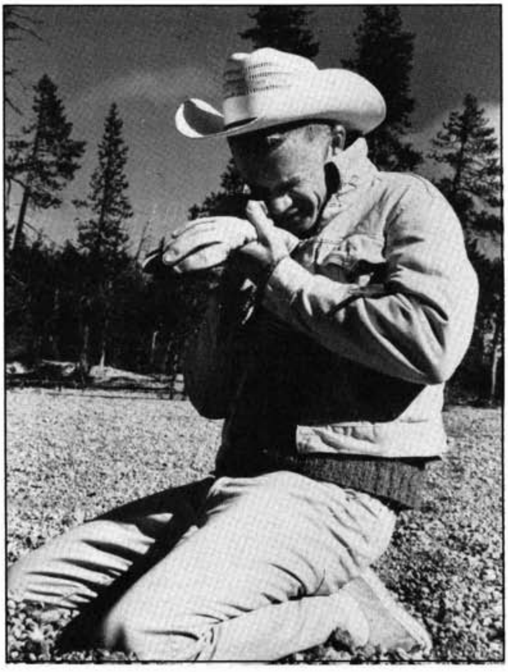


Photo 16. Astronaut Rusty Schwieckart examining a pumice fragment with a hand lens in the Newberry Caldera near Bend, Oregon. (Photograph by the author)

Photo 17. Geologist Dr. Aaron Waters (left) lecturing to group of astronaut students near Bend, Oregon. Astronaut students are Al Bean (rear, dark cap), Charlie Bassett (light western hat), Buzz Aldrin (bareheaded), and C. C. Williams (behind Aldrin in light parka). (Photograph by the author)

Photo 18. Group of astronauts and geologists examining a large lava tube near Bend, Oregon. (Photograph by the author)

Instruction at Meteor Crater, Arizona, and at the Atomic Energy Commission Nevada Test Site (NTS) helped prepare the astronauts for dealing with impact craters. Meteor Crater is the most recent and best preserved terrestrial impact crater, and the Sedan Crater at NTS showed many features peculiar to explosion craters, such as an overturned rim. Shoemaker, of course, was the local expert for the Meteor Crater trip. He did an excellent job of relating this structure to the impact craters on the Moon, despite the fact that Meteor Crater is formed entirely from sedimentary rocks. The overturned rim, surrounding ejecta deposits, and fall-back units could be clearly identified, and the astronauts performed independent exercises to identify and document these and other features (Photos 21–22). Some years later, a group of astronauts toured the Ries Crater in southern Germany to see the structures and breccia textures associated with a much larger (24-kilometer diameter) impact structure.

Photo 19. Astronaut Elliott See inside a large tree mold in a basalt flow in southern Oregon. (Photograph by the author)

Photo 20. Astronaut Ted Freeman discussing with a colleague the orientation of a layer of rock in Valle Grande near Los Alamos, New Mexico. (Photograph by the author)

Photo 21. Astronauts Charlie Bassett (left) and Roger Chaffee making and recording field observations on the rim of Meteor Crater, Arizona. (Photograph by the author)

The Hawaiian Islands offered an incomparable display of recent basaltic volcanic features. Here, except for the abundant plants and the lack of meteoritic impacts, both rough and smooth surfaces of lava flows could be compared to the Moon's surface. The landscape of the higher elevation portions of the "Big Island" could be matched only by that of central Iceland, which we visited some months later. The charm of Hawaii lured even the least interested student into remaining relatively alert and inquisitive. In January 1965, it was hard not to be excited about standing on an active volcano. Also, the astronauts were eagerly anticipating the first Project Gemini flight launch, with Gus Grissom and John Young on board, which was only two months away.

In order to study more silica-rich pyroclastic rocks, we went to Katmai National Monument in Alaska, where a huge explosive eruption of pumice and ash had filled the sky and river valley in 1912. Coming from the crater Novarupta, the eruption had drained support from under Mt. Katmai, causing the summit to collapse,

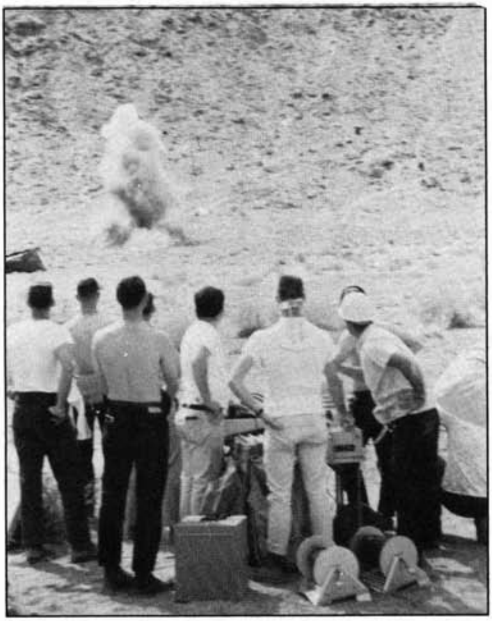
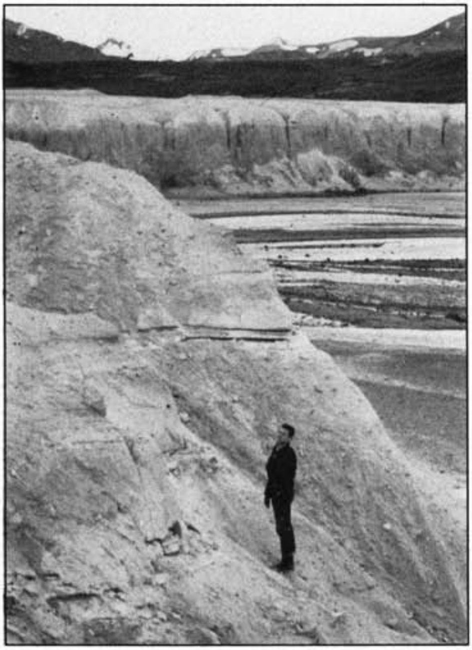


Photo 22: Group of geologists, geophysicists, and astronauts observing a geophysical data "shot" on the floor of Meteor Crater, Arizona. (Photograph by the author)

Photo 23. The author (left) with astronauts C. C. Williams and Bill Anders taking photographs on the rim of Novarupta Crater, Mt. Katmai National Monument, Alaska. (Photograph by the author)

Photo 24. Astronaut Charlie Bassett observing layering and grain size in the toe of the ash-flow in the Valley of Ten Thousand Smokes, Mt. Katmai National Monument, Alaska. (Photograph by the author)



thereby reducing the height of the mountain by 1,500 feet (Photo 23). The ash flow deposit from the eruption had so many fumaroles and vents discharging steam that it became known as the "Valley of Ten Thousand Smokes," though no fumaroles from this deposit are active now (Photos 24–25).

We stayed at Brooks Lake Lodge and were flown each day to our exercise area on the ash flow deposit. Transportation was provided by helicopters of the Air-Sea Rescue Group based at King Salmon (Photos 26–27). Some of the flight equipment made me a little nervous because it had been pretty badly shot up, probably in southeast Asia. Though neatly patched, it was clearly stenciled "UNFIT FOR COMBAT SERVICE." The pilots knew their business,

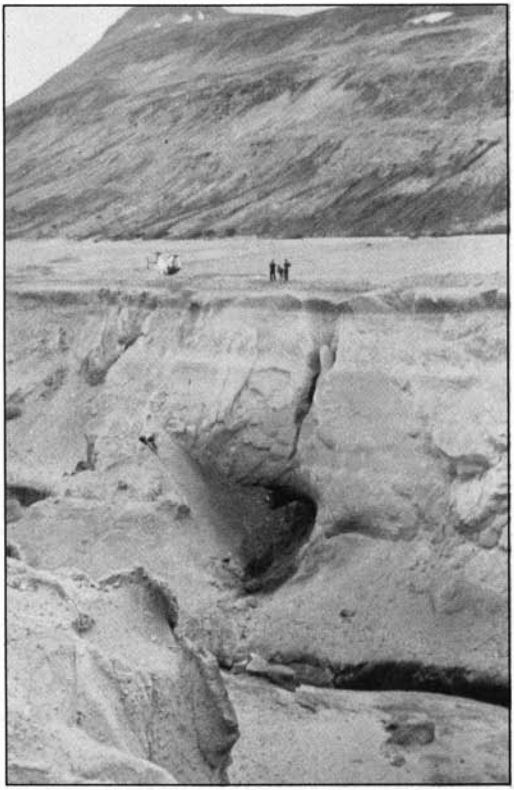


Photo 25. Field party of astronauts with instructor observing structure of the ash-flow visible in the wall of a steeply eroded arroyo on the top of the ash-flow in the Valley of Ten Thousand Smokes, Mt. Katmai National Monument, Alaska. (Photograph by the author)

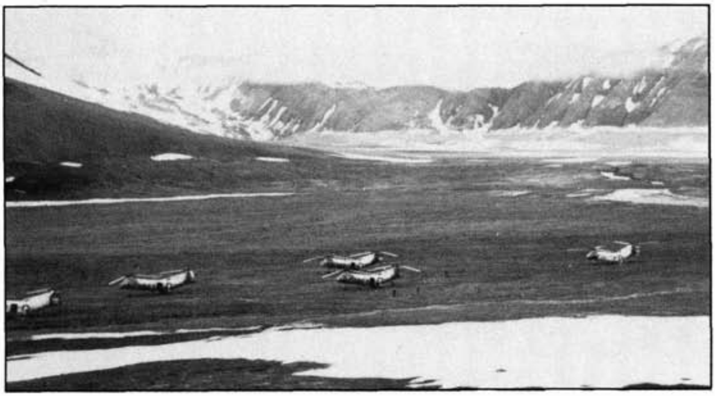


Photo 26. The fleet of air-sea rescue helicopters that provided the field transportation in Mt. Katmai National Monument, Alaska. (Photograph by the author)

however, and our helicopter rides to and from the field areas were uneventful.

The locality itself was also not without its hazards. Each evening a large bear made its way through the camp on the way to the garbage dump. We looked around carefully before walking between the dining room and the cabins. Although the bear probably would have ignored us, avoiding confrontation seemed the best policy.

One of the photographers was an avid fisherman, and with a brook full of rainbow trout and arctic grayling nearby, he was up at six every morning, tickling the water with dry flies. We all appreciated his rapport with the fish when, with the help of the cook, he provided us with a rainbow trout breakfast.

As on previous trips, we had the astronauts play the "Moon game." A pair of astronauts were placed in a field location and instructed to pretend they were on the Moon. Then they had to carry out the most important field observations: planning traverses and collecting samples. The astronauts spoke into a radio-microphone while we taped their transmissions for critical evaluation. It was an instructive exercise, and some competitive spirit quickly developed between different pairs of students. Some of the astronauts were

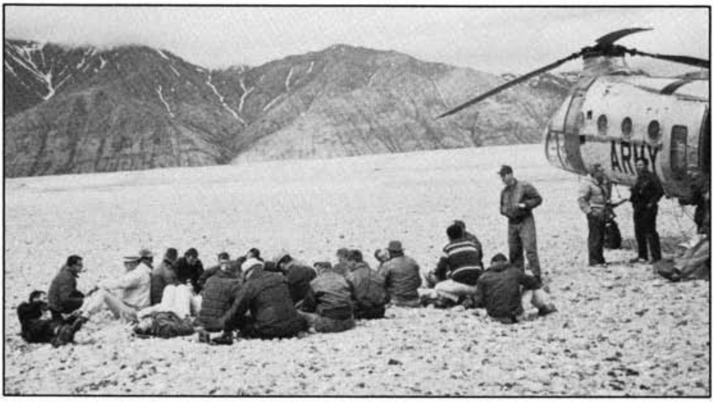


Photo 27. The astronauts and instructors taking a lunch break near the helicopters on top of the ash-flow in the Valley of Ten Thousand Smokes, Mt. Katmai National Monument, Alaska. (Photograph by the author)

convinced they would have a better chance of being selected for a lunar surface mission if they performed well in the geology training course. While this perception was perfectly reasonable, I never found any evidence of this factor in the crew selection process. Comments regarding the abilities of different astronauts were off the record and were only informally passed among the geology instructors. The flight crews appeared to be selected by Deke Slayton and Al Shepard, with Dr. Chuck Berry, the chief medical officer, empowered with final veto. Little other input seemed to bear on the selection process.

In June 1965, the selection of six "scientist astronauts" was announced by NASA, yielding to increasing pressure from the scientific community. The candidates selected had been nominated by the National Academy of Sciences and had passed numerous medical examinations. Among the group was my old schoolmate from Harvard, Jack Schmitt, the only scientist-astronaut in the group whose scientific training was in geology. The scientist-astronauts had to take jet flight training as their first task, an activity that caused considerable anxiety for some of them. We didn't see much of them for the first few months.

Early in September 1965, we camped out with a group of astronaut students in the highlands near Medicine Lake, California. Dr. Aaron Waters was the local expert in this area, as he had been in Oregon. Field exercises included the standard "Moon game" and some independent mapping. Because we were camped a long way from civilization, we had a lot of time on our hands in the evenings. Poker games became the standard recreation. You can tell a lot about a man by how he plays poker—at least you think you can. For most of us, playing poker was nothing more than diversion, with too little money at stake for anyone to take it seriously. But Buzz Aldrin came from somewhere else. He could not believe that Chaffee or I could bet 50 cents foolishly, with a pot of three dollars on the blanket, just to try to confuse him. Aldrin had earned a doctorate in astronautics from MIT, and he played poker with the same logical, methodical technique that he had pursued academics. We had to cut the Medicine Lake trip short because a hurricane was approaching Houston and we needed to get back in time to secure our homes and families.

We took one of our best field trips to Iceland. If you want to go to a place on earth that looks like the Moon, central Iceland should be high on your list, as it beautifully displays volcanic geology with virtually no vegetation cover. The summer climate is mild and cool—particularly enjoyable if you just walked off the plane from Houston.

It was a long flight from New York to Iceland, and the airline was very generous with the liquor. We got off the plane in dense fog and stumbled around until someone found the way to the terminal. We checked into the Bachelor Officer's Quarters (BOQ) at the air base, got a few hours sleep, and went to a cocktail party and reception hosted by the base commander. It was a great party, but seemed to go on a long time. Several times I looked out the window to find that it was still daylight. So, I thought, it can't be too late, but I had forgotten how far north we were. Finally, I just couldn't party any longer and made my way back to the BOQ, feeling low in spirit because I didn't have the "staying power" the astronauts had.

When I arrived at the BOQ, I found Charlie Bassett—clearly out of it—talking to himself in the hall. I helped him find his room and a cot and then went to my own room feeling much better.

Our field excercises on the rim of the Askja Caldera went very well. I spent most of my time working with Dave Scott, Gene Cernan, and C. C. Williams. Scott and Cernan were especially adept at

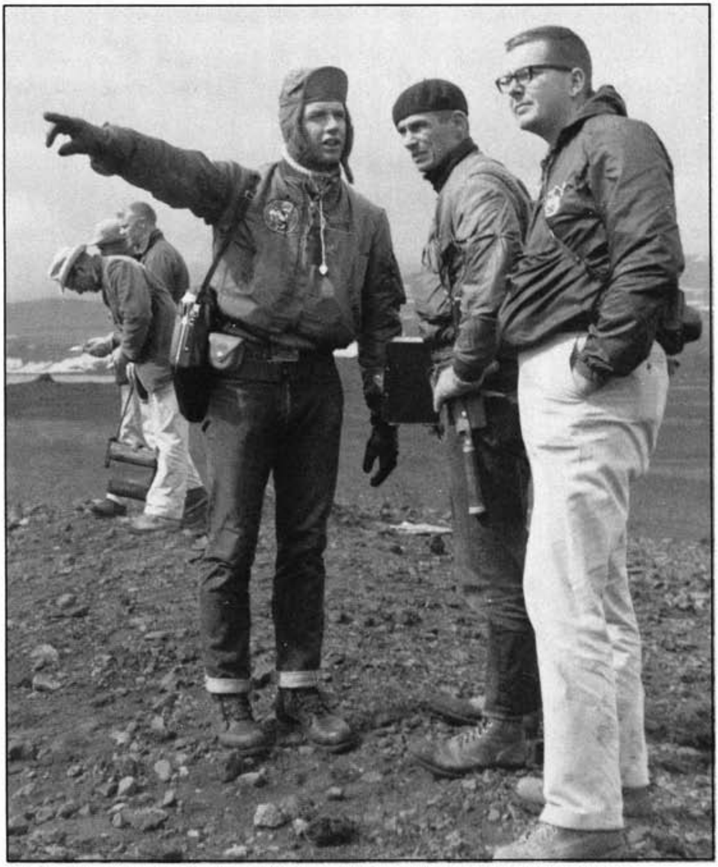


Photo 28. Astronaut Dave Scott pointing out a geologic feature to astronaut Gene Cernan (center) and the author on the rim of the Askja Caldera, Iceland. In the background, geologist-instructor Dr. Don Wilhelms (stooped over) with astronaut Rusty Schweickart and unidentified person. (NASA photograph S-65-39245)

Photo 29. Astronauts Dave Scott (right) and Gene Cernan (black beret) on the steep rim of a small volcanic crater in the Askja Caldera, Iceland. (Photograph by the author)

Photo 30. Astronauts and instructors along steep rim of a small volcanic crater in the Askja Caldera. Field parties are along the same rim as shown from a different vantage point in photo 29. (Photograph by the author)

Photo 31. Astronaut Al Bean climbing up a pile of steaming volcanic cinders in central Iceland. (Photograph by the author)

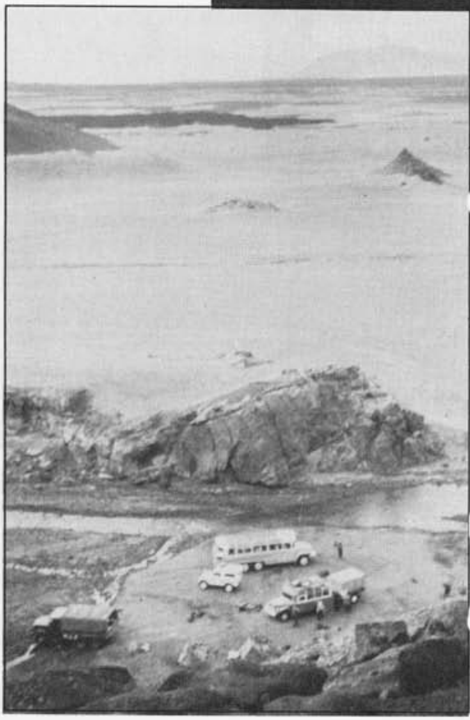


Photo 32. Field parties unloading the bus and supply trucks to set up camp at Drekagil. (Photograph by the author)

unraveling the sequence of geological events along the caldera rim (Photos 28–31). In addition, they knew quite a bit about the rocks.

We spent one night in sleeping bags in a little shelter hut and another night camped out in pup tents at a place called Drekagil (Photos 32–33). While erecting the pup tents, Williams read the proper procedure to us from his Marine Corps manual. He always seemed to have it with him. We had air mattresses to put under our sleeping bags, but the spiny pumice punched holes in them. Consequently, we got very little sleep that night. We also took some trips closer to Reykjavik, where we observed pillow lavas and features of basalt flows (Photos 34–35).

One advantage of working at MSC during missions was having access to the visitor room at Mission Control. However, several thousand NASA employees wanted to enter the visitor room, too. During the most interesting parts of many flights, access to the visitor viewing room was limited to a short period of time. When I mentioned my frustration over this to Ed White, he suggested I try to get into the director's conference room because it had all the most

Photo 33. The finished tent camp at Drekagil, central Iceland. (Photograph by the author)

Photo 34. Dr. Gottmunder Sigvaldessen (left) and astronauts Al Bean and Rusty Schweickart (right) examine the detailed structure of Icelandic pillow lavas. (Photograph by the author)

Photo 35. Astronaut Bill Anders makes a friend in a small Icelandic village. (Photograph by the author)

important displays and voice circuits. I was reluctant to do so, but discovered if I just went in and sat down everyone assumed I belonged there. An "access list" existed but was rarely checked during the excitement of mission operations. The director's conference room furnished a great seat for following the Gemini orbital rendezvous in December 1965.

The increasingly frequent Gemini flight schedule made it hard to get many astronauts together very often. The pace of the field trips slowed, and we initiated a "tutorial" system. Whenever an astronaut had an unexpected schedule gap, we tried to fill it with some practical rock identification excercise or other lab practice. I was assigned to tutor astronaut Roger Chaffee. Chaffee was an eager and good student. He wanted to keep a petrographic microscope at home, so I procured one for him from the lab. My boss was concerned that we were violating law or policy by placing government equipment in private homes, but we did it anyway. We spent hours going through sets of thin sections and hand specimens, mostly of volcanic and shock-metamorphosed rocks. I was encouraged. If Chaffee landed on the Moon, he would be a capable scientific observer.

On February 28, 1966, astronauts Elliot See and Charlie Bassett were killed in a plane crash in St. Louis. While trying to land in poor visibility, their plane hit a building. Both men were well-liked and had worked hard to prepare themselves for Moon exploration. That didn't seem to matter now, but we knew other crew members would make it for them.

The Gemini Program ended with the flight of Lovell and Aldrin on board Gemini XII in November 1966. As with Project Mercury, Gemini was an almost flawless success. Orbital rendezvous was not only possible, it was practically routine. The Apollo-Saturn "Moon rocket" hardware would soon be prominent at the Cape. The Moon was getting closer.

A routine pad test in January 1967 at the Cape resulted in utter tragedy. Grissom, White, and Chaffee (Photo 36) were killed in a flash fire that swept through the pure oxygen atmosphere of their

spacecraft cabin—a particularly claustrophobic and nasty way to die. We were outraged. It should have been clear to any engineer or scientist that, under high pressure, a pure oxygen cabin atmosphere would turn the slightest flame into a holocaust. It was a terrible error in judgement. I attended a funeral service in Seabrook for Ed White. The church was packed. Virtually all the teary-eyed faces were familiar. We all-too-clearly remembered White and his daring

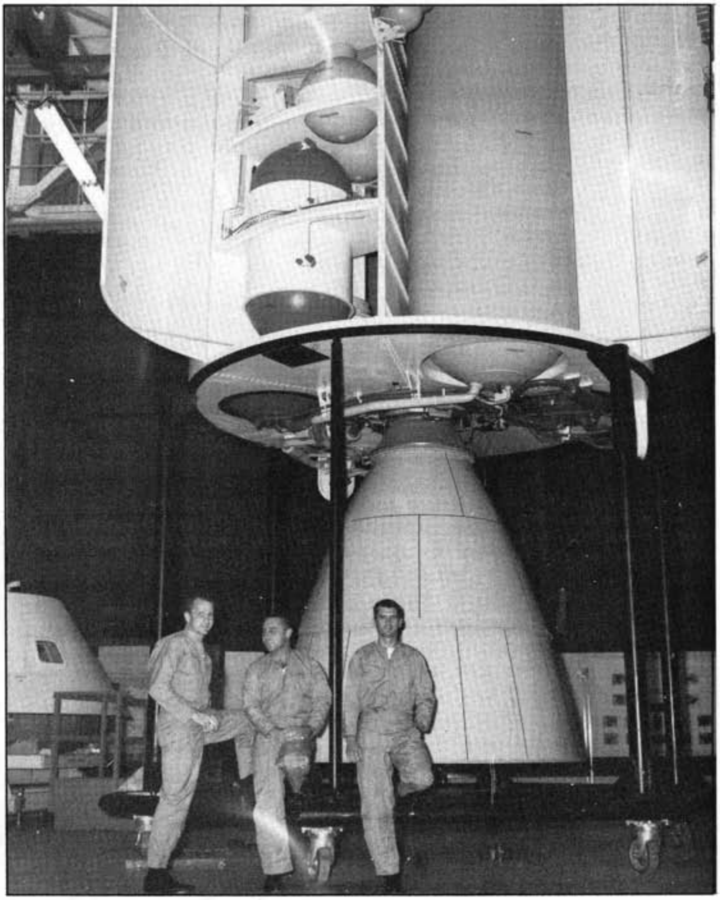


Photo 36. The crew of (left to right) Ed White, Gus Grissom, and Roger Chaffee shortly before the fire that took their lives. (NASA photograph S-66-40190)

Photo 37. Field test of space interface with geology hand tools for lunar missions on a cinder field near Flagstaff, Arizona. (Photograph by the author)

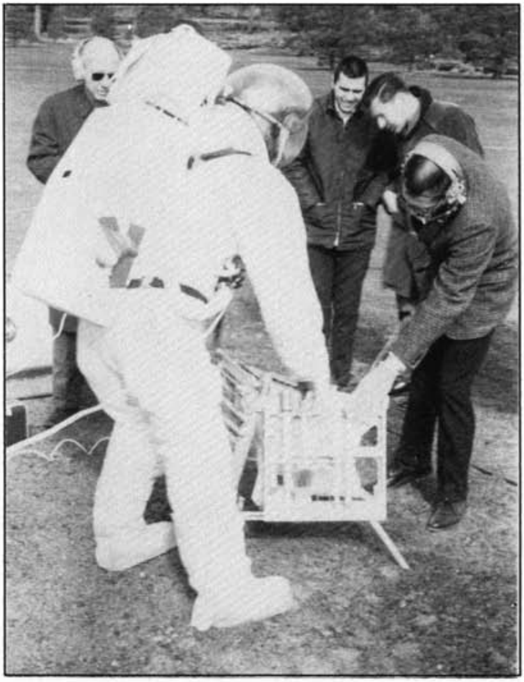


Photo 38. Space-suited technician tests use of prototype geology hand tools for lunar surface missions. Then-future astronaut Jack Schmitt is at the center (hands in pockets) near Flagstaff, Arizona. (Photograph by the author)

space walk. Overhead, a group of jet planes flew in formation with one plane missing. It was one of the saddest occasions I can recall.

Redesign for use of more non-flammable materials delayed the Apollo launch significantly, with the first manned flight scheduled in October 1968. In August, NASA announced the selection of a second group of scientist-astronauts, which included Brian O'Leary, a young planetary astronomer from Berkeley. O'Leary was excited to be at the space center, but his enthusiasm did not last. Only seven months later he resigned from the astronaut corps.[9]

Now and then I was involved occasionally with some lunar surface mission planning for science experiments and experimental space suit interface testing (Photos 37–38), but most of my time was spent with the Lunar Receiving Laboratory and other duties. My association with the astronaut geology training program slowly dwindled as the Apollo program moved ahead.

In October 1967, we heard that C. C. Williams lost his life in a flight accident over Florida. Once again, we were brutally reminded that flying machines are forgiving of neither pilot error nor equipment failure.

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[9]B. O'Leary, *The Making of an Ex-Astronaut* (Boston: Houghton Mifflin Co., 1970).

III. Lunar Receiving Laboratory

Action was quickly taken after the memorandum outlining the need for a receiving facility for the samples arrived at the directorate level. The lunar samples could suffer degradation due to terrestrial contamination unless they were carefully handled in a controlled environment. For example, contamination with trace elements and isotopes could lead to false conclusions about the age, history, and origins of the Moon rocks. Furthermore, some analyses and examinations were either critically time urgent or were necessary to distribute the samples intelligently to the proper specialists.

Flory and I nervously awaited a reply from the directorate level. We feared the worst—not getting any reply at all—but our wait was short. We were summoned along with our boss to a meeting with a member of the directorate staff, Aleck Bond, a cautious, methodi-

cal, and reasonable man who listened to our case and asked appropriate questions. Bond was convinced we were wise to an aspect of the Apollo missions that had been overlooked. He advised us to give the receiving laboratory our full attention and to prepare a more detailed set of requirements for the facility. When we had assembled the facility description, he would review it with us and present it to his boss, Max Faget.

Our progress in preparing the facility proposal was crippled by our inability to predict the properties of the lunar samples. Would the samples react with the Earth's atmosphere? What were their major and trace element compositions? We decided to prepare for the worst case; the samples should be maintained in an environment as close as possible to that of the lunar surface. This meant that initial handling and examination of the lunar samples would have to be performed in sophisticated, hard vacuum chambers at very low total gas pressure—technically possible, but expensive and operationally complex.

With Bond's help, we presented our plan to Faget, who recognized the significance of a lunar sample receiving laboratory. He was concerned, however, about how to establish the detailed requirements and specifications for the facility in order to convince the scientific community that the lab was necessary and reasonable. Faget suggested we present our concepts to several NASA advisory committees, particularly the NASA Office of Space Science and Applications (OSSA) Planetology Subcommittee. We prepared visual aids, organized and rehearsed our presentation, and got on the agenda for the next meeting in Washington, D.C. We felt confident about this meeting with fellow scientists, and as we hoped, our presentation was well-received. One member of the subcommittee, Dr. Clark Goodman, a physicist from the University of Houston, was enthusiastic. He suggested forming a "working group" with the proper expertise to advise NASA on the lab's requirements. The effort had to begin immediately in order to have everything ready in time to handle the first lunar samples. We settled on "Lunar Receiving Laboratory" (LRL) as the name for the facility, and the

special advisory committee, first known as the OSSA Ad Hoc Committee, became the LRL Working Group.[10]

Soon we began to hear rumors of concerns over potential biological back contamination from the Moon. Dealing with such contamination would greatly complicate the sample work. The report of the Space Science Board of the National Academy of Sciences from its Conference on Potential Hazards of Back Contamination from the Planets, held in July 1964, sealed our fate. We argued that because of the lunar surface environment the Moon presented no potential hazard. The hard vacuum, large variations in surface temperature, high UV and hard radiation, absence of free water, and constant bombardment of the surface with meteoroids would discourage the most resilient microbes. If you wanted to design a sterile surface, you would make it as much like the Moon as possible. Furthermore, space scientists generally agreed that secondary ejecta from lunar impacts reach the Earth more or less continuously, and no infections were related to contact with meteorites. All the same, when pressed with questions, we could not guarantee the lunar surface and shallow subsurface were sterile. The design requirements for the LRL took on new dimensions.

We anticipated performing the first descriptions of the lunar samples in hard vacuum, but we hoped if the samples were nonreactive with dry nitrogen that we could execute the preliminary examinations in one-way barrier glove boxes. Now we would have to perform the procedure behind two-way, gas-tight biological barriers—one way to protect the samples from terrestrial contamination and the other way to protect the terrestrial biosphere from potential lunar organisms. In addition to providing quarantine testing for the lunar samples, we had to provide quarantine housing for the crew and the returned spacecraft. NASA once again needed expert advice and requested the creation of an Interagency Committee on Back Contamination, to be staffed by official representatives

[10] J. C. McLane, Jr., E. A. King, Jr., D. A. Flory, K. A. Richardson, J. P. Dawson, W. W. Kemmerer, and B. C. Wooley, "The Lunar Receiving Laboratory," *Science*, vol. 155 (1967), 525–529.

of the U.S. Public Health Service, National Academy of Sciences, U.S. Department of the Interior, U.S. Department of Agriculture, and NASA. This committee continued to follow the design, construction, and check-out of the LRL from a biological hazard-containment perspective.

We knew nothing about two-way biological containment, so we visited some laboratories involved in the business. The U.S. Public Health Service Communicable Disease Center in Atlanta and the Fort Dietrich, Maryland, high hazard pathogen containment facilities were particularly instructive. They handled high hazard pathogens with success, only rarely losing a lab technician because of personal negligence or accident. I held my breath a lot while touring the facilities. One thing was clear: working on lunar rocks with microscopes and even relatively simple analytical equipment behind barriers was not going to be easy.

With the LRL Working Group, we strived to nail down the scientific requirements for the lab. At the same time, we were coordinating the quarantine and pathogen detection requirements with the Interagency Committee. The biological requirements involved a number of artistic, if not arbitrary, decisions. For example, in order to ascertain the length of the quarantine period, we had to estimate the incubation period of the mythical microbes. Similarly, in case of a break in the biological barrier, we needed to know how to sterilize the potentially contaminated area. Should we saturate the area with sodium hypochlorite, fuming nitric acid, or Scotch whiskey? What did it take to kill a potentially harmful lunar organism? "Heat to incandescence!" was a favorite phrase of the time. After criteria for sterilization of the lunar samples were established, we had the option of sterilizing a sample and working with it outside the awkward containment system—provided the process of sterilization itself did not seriously degrade the sample.

During the quarantine period, many biological test systems would be exposed to the lunar samples to detect any pathogenic reactions. We were concerned about the scale of the quarantine testing because each test required lunar samples. We wanted to keep

the amount of lunar samples used for quarantine testing to a minimum. Obtaining scientifically priceless samples from the Moon and then using a significant portion of them for injections into mice or soil or wheat seedlings seemed absurd. At one point, Dr. Harold Urey, Nobel Laureate in chemistry and an enthusiastic student of the Moon, volunteered to eat some of the lunar sample himself if it would simplify the quarantine requirements. In the end, voices of reason prevailed, and the scope and duration of the quarantine were something NASA could live with. The spacecraft would be returned to the LRL, sealed, and isolated for the duration of the quarantine. The crew would be sequestered in a special habitat in the recovery area, returned to the LRL, and isolated in the Crew Reception Area there, where they could be debriefed across a biological barrier. The Crew Reception Area was a vacant hotel. It was designed to house the three-man crew, some support personnel, and any scientists or technicians exposed to potential lunar pathogens in case of an accidental break in the biological barrier.

When we compiled a nearly complete set of requirements for the LRL, NASA requested proposals for the detailed design of the lab. Contracts also were signed for the fabrication of the high vacuum system in which the samples would first be opened and visually examined. Similarly we initiated design and fabrication of various gas-tight glove boxes required for quarantine testing and the preliminary mineralogical, petrological, and geochemical examinations.

The LRL was taking so much time that the directorate decided to form a small organizational unit, or "office," whose primary responsibility was the LRL. Jim McLane, an experienced NASA engineer, was selected to head the office. Although McLane was uncomfortable with the science involved in the LRL, he was a level-headed, practical manager who knew how to get things done within the space center and the agency.

Utility and excavation work began on the LRL site, and the lab began to take shape. Two special scientific laboratories were identified as part of the LRL. One of these, the Radiation Counting Labo-

ratory, a state-of-the-art gamma ray spectrometry laboratory fabricated from low radiation background materials, was constructed 50 feet below the ground floor offices and housed the latest large-volume detectors and electronics (Figure 2). This facility was important for measuring the natural radioactivity of the lunar samples, some of which is caused by cosmic rays. Because the radioactivities of

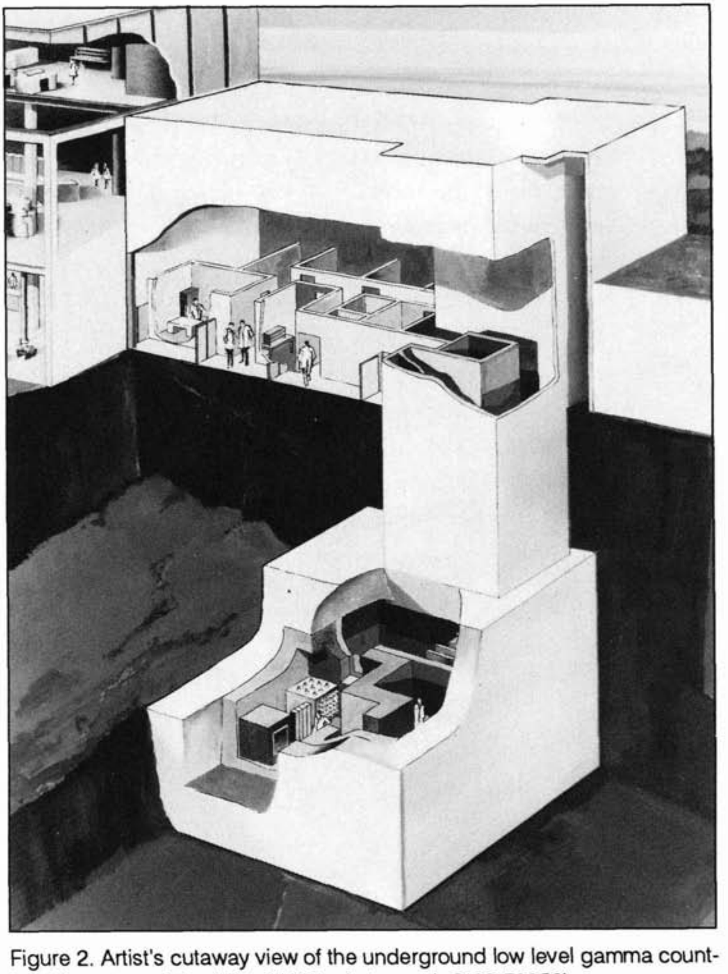

Figure 2. Artist's cutaway view of the underground low level gamma counting laboratory of the LRL. (NASA photograph S-66-50256)

some nuclides have very short half-lives, they would have to be measured during the quarantine period or the data would be lost. Even with the cosmic ray–induced activity, the total radioactivity in lunar samples was expected to be low—thus the need for very sensitive, low background measurements.

Another specialized lab, the Gas Analysis Laboratory, constituted the third floor immediately above the main vacuum system (Figure 3). The samples would be returned in two vacuum-sealed metal boxes, enabling scientists to analyze any gases emitted from the samples when the box was opened in the main vacuum chamber. Also, gases that might be released during unpackaging or splitting of individual samples could be monitored by a sensitive gas chromatograph–mass spectrometry system. Part of these early measurements would include gases evolved from a specially collected sample maintained at ultra-high vacuum.

The general plan of sample flow called for 1) introduction of the

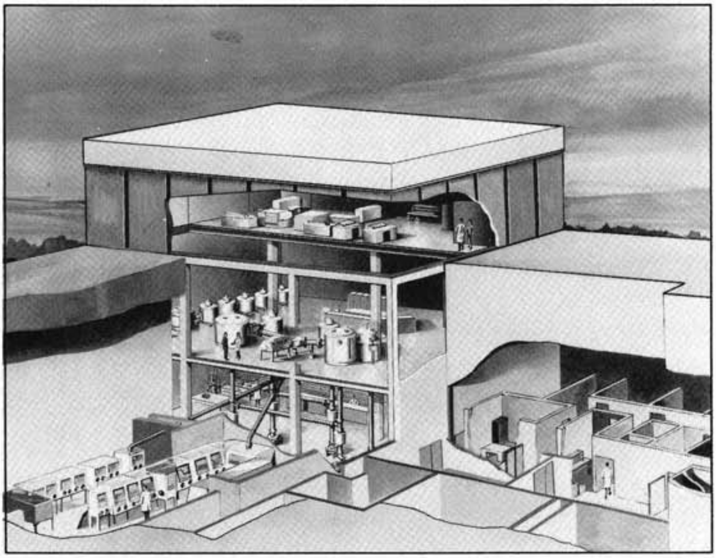

Figure 3. Artist's cutaway view of the LRL gas analysis laboratory (third floor), main vacuum laboratory (second floor), physical sciences and biosciences test laboratories (lower left), and office space (right). (NASA photograph S-66-50257)

rock boxes into the main vacuum system, 2) opening of the rock boxes, and 3) visual inspection of the samples in the main vacuum system. Two small chips of each sample would be taken. One would be sent down a metal pipe to the physical-chemical test area where it would undergo preliminary scientific examination and characterization; the other would go down a similar pipe to the quarantine test area for pathogen testing. Specially packaged samples would be removed from the vacuum system, sealed in three biological barriers, and transported to the Radiation Counting Laboratory.

The bulk of each sample would be retained in the high vacuum system for long-range storage under ultra-clean conditions in specially prepared containers. Storage and curation of the lunar sample collection would be an important long-term responsibility of the lab.

We were under pressure from the LRL Working Group to appoint a leader for the LRL. McLane was offered the job but declined because he felt more qualified for an engineering assignment. The Working Group identified Dr. P. R. Bell of the AEC Oak Ridge National Laboratory as a potential candidate. A well-respected scientist, Bell had a lot of experience with high-vacuum systems. Also, he had served on the LRL Working Group and was intensely interested in the LRL and the lunar samples. Bell agreed to interview and was subsequently named director of the LRL (Photo 39).

The MSC science staff knew Bell from his contributions to the Working Group, but we got to know him a lot better as a passionate, energetic man. He tended to be opinionated, but frequently he was right. His ability to take part in an argument without taking it personally was one of his greatest traits. Meetings in Bell's office were often audible at the far end of the hall, but he gave everyone a thorough and fair hearing. No matter how heated the discussion became, tomorrow was a new day.

During the construction and equipment installation phase, we spent a lot of time identifying construction errors by checking actual "bricks and mortar" against blueprints and specifications. We be-

Photo 39. The Lunar Receiving Laboratory (LRL) during construction at the NASA Johnson Space Center, aerial view looking northwest. (NASA photograph S-67-20397)

gan to publicize the laboratory to the community of scientists who would be working with lunar samples (Photos 40–41). In order to qualify to receive lunar samples for research, researchers had to submit a lengthy proposal stating the nature and amount of sample required, purpose of the research and the means by which it would be accomplished, qualifications of those working with the sample, compliance with sample security requirements imposed by NASA, and information on a number of other matters. This proposal was reviewed by a peer evaluation process, and the successful proposers were designated "Lunar Sample Principal Investigators." This designation meant the investigators would receive substantial NASA funding to upgrade and modernize their laboratories and to train and support a sample analysis team. Investigators were virtually guaranteed to receive lunar samples for analysis if the correct

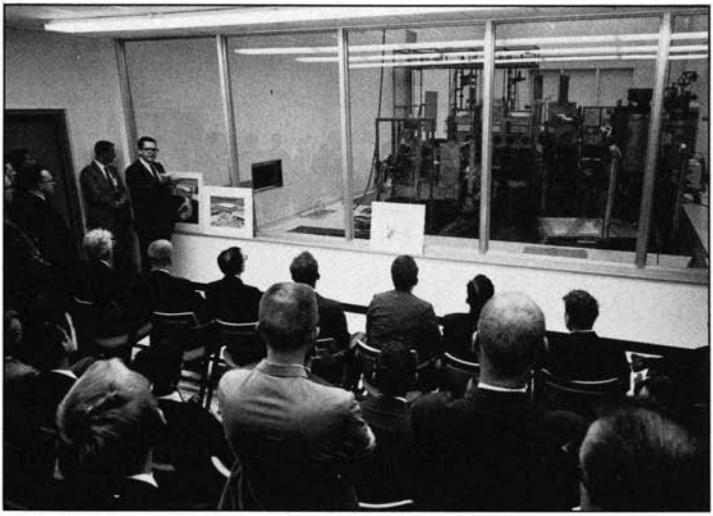

Photo 40. A group of lunar sample investigators getting an orientation lecture from the author (left) on the operation of the LRL main vacuum laboratory. The group is in a visitor viewing room adjacent to the vacuum laboratory, which is only partially completed. (NASA photograph S-67-45454)

Photo 41. Author (left) shows Prof. Wolf von Engelhardt of the University of Tubingen, West Germany, details of the two-way biological barrier cabinetry in which the lunar samples will be examined in a dry nitrogen atmosphere. (NASA photograph S-67-45452)

samples for the work were returned in sufficient abundance. In addition, researchers could count on receiving support from NASA as long as they turned in important and interesting lunar sample research results. Naturally, the status of lunar sample principal investigator was highly coveted.

One of the worst jobs associated with the LRL was writing the detailed procedures for all the laboratory operations, an Interagency Committee prerequisite for the facility to be certified for quarantine operations. NASA managers liked to see volumes and volumes of procedures for everything. We spent a lot of time, together with support contractors, generating prodigious piles of paper.

The scientific functions of the LRL were carried out by a small group of resident scientists who were thoroughly familiar with the facilities, but the LRL also relied on a number of expert visitors from universities and other government agencies for much of the preliminary scientific work. Two groups were involved with LRL lunar sample operations: 1) the Lunar Sample Preliminary Examination Team (LSPET, or PET), which performed all the initial sample investigations in the lab on a double-shift basis, and 2) the Lunar Sample Analysis Planning Team (LSAPT), which evaluated the sample data and recommended the precise distribution of lunar samples to the scientific community after the quarantine period. LSPET members had to be selected and trained as soon as possible in order for them to gain sufficient experience with actual sample operations and to comprehend the written procedures before the lunar samples arrived. We suggested potential team members to NASA headquarters, and with few exceptions they were appointed.

Shortly after I moved into my office in the LRL, I heard that Harold Urey was looking for me. I knew Urey had been appointed as a visiting scientist. I had heard one of his lectures but couldn't imagine why he wanted to see me. While I was on the telephone trying to locate him he walked in the door. We had met previously, but this was our first opportunity to converse privately. It turned out that he wanted to talk about the Moon. A full Moon photograph hung on my office wall, and we discussed the possible origins of

various features. Then he came to the question that really interested him: What were the lunar maria composed of? To me, it was a simple question, and my answer boiled down to a composition of rather normal basalt. Disappointed in my response, Urey stated his reasons for believing that the maria might be rich in organic compounds and be some variety of carbonaceous chondrite, a rare organic-rich variety of meteorite. We strongly disagreed over the matter, and after an awkward moment as we realized our minds were firmly set on the issue, we shifted the topic of the conversation to comets. Comets were safe ground since neither of us knew much about them and our ideas about comets were still flexible. We continued our genial conversation for more than an hour.

I was appointed curator of the LRL in September 1967, landing me the responsibility of all the sample collection, preparation of catalogs, logging sample data, dividing and distributing samples to authorized investigators, and keeping track of sample contamination histories, etc. It was a sizable responsibility, one which I took very seriously.

In early 1968, one of our big bosses phoned to ask what we could show to a very important visitor who might spend 15 minutes in the LRL. After Bell and I conferred, we decided to take the VIP to the main vacuum laboratory to show where the samples would be first examined. Our response only marginally satisfied the boss because he wasn't sure if the VIP would be allowed to go to the second floor. That puzzled us, and we were curious about the identity of the mystery visitor. A few weeks later, the big boss called again to tell us that a man was coming to talk about a possible VIP visit and requested that we cooperate with him. The man who came into Bell's office gave us a name but no organization. He was accompanied by a staff member from NASA-MSC security. We talked with the man, who took notes, for half an hour. We were told the VIP would have 10 minutes to spend at the LRL and that we would get details later. Bell, whose vision was badly impaired, mused, "I wonder who it is?" "P.R.," I said, "the man was taking notes on White House stationery." The color drained from Bell's face.

On April 1, 1968, President Lyndon Johnson visited the NASA Manned Spacecraft Center. He came to the LRL accompanied by a peculiar entourage of about 10 people and a small dog that took every opportunity to mark this marvelous new territory, an activity his mistress pointedly ignored. Pistols protruded from the jackets of two of the men in the party—probably Secret Service men without their lapel pins pretending to be part of the presidential group. Various bureaucrats and hangers-on jockeyed for position to be in photographs with the president. The little dog ran out of pee. The whole affair had a "banana republic" or "comic opera" flavor. After Bell and one of our big bosses gave a 10-minute presentation, the president and the party were rushed away. On the occasion of his visit to MSC, President Johnson announced the creation of the Lunar Science Institute.[11]

We began practice operations with simulated lunar samples. One of the biggest problems we faced was working in the main vacuum chamber with its space suit gloves. Sample operations with the gloves were clumsy and slow, and the gloves commonly developed small atmospheric leaks. Early in the design stage, a decision was made to use a pressure glove system instead of mechanical manipulators in the vacuum chamber. In retrospect, this probably was an error. Sample operations elsewhere in the quarantine test and mineralogical, petrological, and geochemical glove boxes went fairly well. These just took a little practice.

The simulated sample operations were tricky because we didn't know for sure which samples were most like the ones we would receive from the Moon. O'Keefe still supported the idea that tektites came from the Moon. Urey argued that the lunar maria were composed of carbonaceous chondrites. Others suggested that different types of meteorites came from the Moon: ordinary chondrites, basaltic achondrites, mesosiderites, and so forth. For our test runs, we

[11]Now known as the Lunar and Planetary Institute, located in the remodeled West Mansion on the shore of Clear Lake at 3303 NASA Road One, Houston, Texas 77058.

used a mixture of terrestrial volcanic rocks and meteorites, as well as some shock-damaged rocks.

In April 1968, we organized a meeting of all of the mineralogy/petrology principal investigators on the east coast to precede the annual meeting of the American Geophysical Union (AGU), which would be attended by many of the investigators. The meeting, held in a Baltimore hotel, went well but it coincided with the riots in Baltimore and Washington. Bright flames and smoke were visible from the hotel windows. Many shops on the street were looted. The hooves of the mounted policemen's horses clattered on the pavement. I don't believe we made a very good impression on our foreign visitors. When the meeting was over, I took a cab to Washington to the AGU meeting. I rode with a Baltimore cabbie who did not know his way around Washington. We drove through some of the area worst hit by the riots, crossing fire hoses and passing burned-out buildings, but we encountered no trouble. Everyone just looked tired, especially the National Guard. The riots were over.

A big Saturn rocket with its Apollo 7 crew of Schirra, Eisle, and Cunningham lifted off from the Cape and went into low Earth orbit in mid-October 1968. The Apollo program space flights had begun. The first lunar landing and sample return were only months away.

IV. Tektites and Meteorites

Tektites are high-silica glassy objects, ranging in size from microscopic to weighing a pound or more. Superficially, they can resemble corroded pebbles of obsidian (Photo 42). From the beginning of scientific work with tektites, they were found scattered about the surface of the Earth in many localities, with no apparent relationship to local geology. This fact led F. E. Suess in 1900 to conclude that tektites were a glassy variety of meteorite. Many other ideas followed, and some investigators changed their minds many times. Vexed by the tektite origin problem, well-known geochemist Henry Faul stated, "To anyone who has worked with them, tektites are probably the most frustrating stones ever found on earth."[12] Part of the frustration resulted from lack of data on the

[12]For a technical summary of the tektite problem see E. A. King, "The Origin of Tektites: A Brief Review," *American Scientist*, vol. 65, no. 2 (1977), 212–218; or S. R. Taylor, "Tektites: A Post-Apollo View," *Earth Science Review*, vol. 9 (1973), 101–123.

field occurrences of some of the tektites. A portion of my dissertation work sought to determine the field relationships of the tektites found on the Georgia Coastal Plain. Barnes, who visited some of the tektite localities in Georgia, had little success either in finding new specimens or narrowing down the stratigraphy of their occurrence. There was an apparent "age paradox" with the Georgia tektites. Analyses gave radiometric ages of about 34 million years, but tektites were thought to exist on a Miocene formation, which was considerably younger.

I contacted the Georgia State Geological Survey, and they agreed to furnish a truck for my work. A local gentleman, Will Sellers, had previously found a tektite near his home at Jay Bird Springs. I had to start somewhere, so I decided to visit him. He lived alone in an old weathered house on a small country road. He had little to do besides sit on his front porch. Needing some local contact to get me on private land and keep me out of trouble, I asked him if he would agree to act as my "field assistant" for the next month. He agreed to help but said I would have to pay him. When I asked what he thought a fair wage would be, he surprised me by saying, "Two

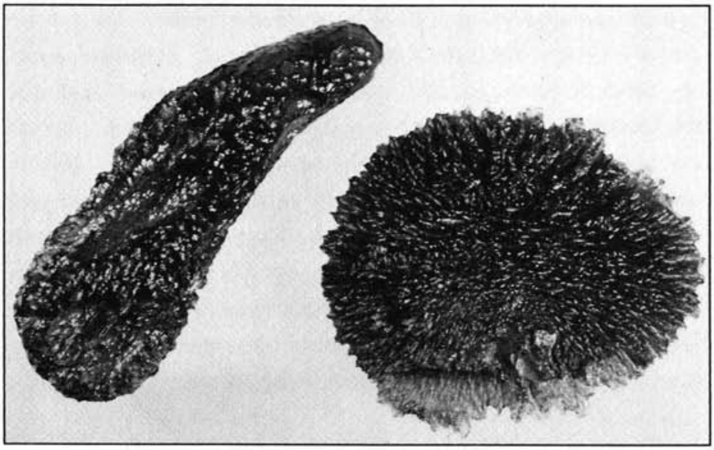

Photo 42. Transparent green tektites from Bohemia, Czechoslovakia. Length of drop-shaped piece is approximately five centimeters. (Photograph by the author)

dollars a day." Sellers proved to be invaluable because everyone in the county knew and liked him. During the course of the field work, we found two new tektite specimens, purchased two more, mapped the entire surficial geology of Dodge County, and managed to avoid a dozen portable propane-powered white-lightning stills. Although I obtained a lot of new information about the Georgia tektites and their occurrence, nothing I turned up seemed to bear on the important questions—how and where did the tektites originate?

By the time I arrived at NASA in late summer 1963, only three possible origins of tektites were seriously being considered: 1) origin from lunar volcanoes, 2) origin as melted ejecta from meteoroid impacts on the Moon, and 3) origin as melted ejecta from large meteoroid impacts on the Earth. The lunar volcanic origin theory fell by the wayside because it did not have a strong champion and it was generally believed that lunar volcanoes were not sufficiently energetic to accelerate volcanic melt to lunar escape velocity.[13] Rejecting the lunar volcano idea left the two impact origin ideas, which were essentially the same except for the location of impact. O'Keefe had supported the idea of a lunar origin for tektites in a series of papers beginning as early as 1960, primarily on the basis of theoretical arguments. The supporters of a terrestrial origin for tektites were frustrated because their only strong argument lay in the chemical similarity of tektites to Earth materials—and the chemical composition of lunar rocks was unknown. Four occurrences of tektites were known at that time: two localities in Czechoslovakia and one each in the Ivory Coast, North America, and Australia and southeast Asia. The youngest group of tektites in Australia and southeast Asia contained specimens that clearly showed two melting periods—the original melting to make the bulk of the glass and a second period of partial melting on one side apparently caused by atmospheric ablation. A series of glass abla-

[13]It is interesting to note that this idea was resurrected years later by O'Keefe when it became apparent that tektites did not come from the lunar surface. See J. O'Keefe, *Tektites and Their Origin* (New York: Elsevier Scientific Publishing Co., 1976).

tion experiments conducted at the NASA Ames Research Center by Dean Chapman and Howard Larson[14] reproduced the shapes of the ablated tektites almost exactly. Chapman and Larson argued that the tektites had to originate from the Moon; otherwise, the detailed shape of the ablated layer and the geometry of the ring-waves formed on the ablation-melted surface would be different. The experiments provided powerful support for the lunar hypothesis, which was forcefully presented by Chapman. The arguments raged. Barnes and Urey were firmly committed to a terrestrial origin. Adding to the excitement was the anticipation everyone felt in knowing a final answer was only a few years away.

A junior colleague of O'Keefe's at the Goddard Spaceflight Center found the very high pressure silica mineral coesite in tektites.[15] This discovery further supported the impact origin because coesite is known to form on the Earth's surface only in impact craters. Of course, it might also form in cratering events on the Moon's surface.

It was gradually realized that the Czechoslovakian tektites came from Ries Crater, a large impact crater in southern Germany. Radiometric age dating showed that the Ries Crater and the Czechoslovakian tektites were both 15 million years old. Likewise, the Ivory Coast tektites were found near the Bosumtwi Crater in Ghana, and both the crater and the tektites were dated at 1.3 million years. This connection furnished strong evidence to most impartial observers that the impacts that formed craters in the Earth also formed tektites.

My personal research with tektites continued from time to time, and I contributed to a better understanding of the physical properties, inclusions, and field occurrences. However, I was unsuccessful

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[14]D. R. Chapman and H. K. Larson, "The Lunar Origin of Tektites," NASA Technical Note D-1556 (Feb 1963), 66 pp. Also, D. R. Chapman and H. K. Larson, "On the Lunar Origin of Tektites," *Journal of Geophysical Research*, vol. 68 (1963), 4305–4358.

[15]L. W. Walter, "Coesite Discovered in Tektites," *Science*, vol. 147 (1965), 1029–1032.

in obtaining data that uniquely pointed to either a terrestrial or a lunar origin.

Charlie Schnetzler finished his Ph.D. work at MIT and was hired at the NASA Goddard Space Flight Center, where Walter and O'Keefe were his colleagues. Schnetzler continued to work with his graduate school professors, Drs. Bill Pinson and Pat Hurley, who were strong supporters of a lunar origin for tektites. In 1966 they investigated the strontium/rubidium age and isotope systematics of the Ivory Coast tektites along with rock materials from the nearby Bosumtwi Crater in Ghana. They found that not only did the tektites and crater rocks lie on the same isochron and their isotope systematics were virtually identical, but that the isotopic ratios were very unusual. They concluded that "the evidence available at present suggests that the Ivory Coast tektites are most probably the fusion products of meteoritic impact at the Bosumtwi crater site"—a dramatic change of opinion for this research group. The evidence and arguments that they presented were quite convincing.[16] Schnetzler's work was proof of a terrestrial origin. His ideas were accepted by almost everyone except, curiously, his own colleague, O'Keefe, who continued to cling to the lunar origin idea.

At the time, I was working with a Czech researcher to determine the cause of color variations in an unusual Czechoslovakian tektite we had borrowed from the Prague Museum. We believed it was appropriate for us to present our results at the International Geological Congress to be held in Prague in August 1968. My wife and I arrived in Prague a week early, met my Czech colleague, and travelled to southern Bohemia to investigate the field occurrences of some of the Czechoslovakian tektites. We stayed in small towns and quaint hotels while spending several beautiful days in the field. We visited several tektite localities in gravel pits and farm fields and collected a number of fine specimens. We returned to Prague one day before the congress and behaved like tourists. The people of

[16] C. C. Schnetzler, W. H. Pinson, and P. M. Hurley, "Rubidium-Strontium Age of the Bosumtwi Crater Area, Ghana, Compared with the Age of the Ivory Coast Tektites," *Science*, vol. 151 (1966), 817–819.

Prague were excited about their recent political successes. The Russian yoke was lighter than it had been only months before. The names "Dubcek" and "Svoboda" were on everyone's lips. The mood was almost jubilant.

The opening of the congress was uneventful. Our paper was scheduled for later in the week. On the second day, we heard many low flying jets in the evening and early morning hours, but we slept anyway. On the morning of August 21, we knew something was wrong. We dressed in a hurry and went to the hotel dining room. The staff were in tears. Looking through the large dining room windows, we saw a man excitedly handing out newspapers to the people on the street outside. Then, at the end cf the street, appeared the lead tank of a Russian armored column, coming toward us at a deliberate pace. Young soldiers with submachine guns were lying on their backs on both sides of the tank and watching the rooftops and windows for possible gasoline bombs. We moved away from the windows.

The telephones didn't work for two days, and we could not contact the American Embassy. When I finally got an operating line, a very tired voice told me that an American diplomatic representative would lead a convoy of Americans out of Czechoslovakia the next morning. The convoy would form at a little village called Rudna. We didn't have a car, but I remembered that my old professor, Bullard, and his wife were staying in our hotel. I found Bullard, told him of the embassy plan, and asked if he had a car. He did! It was a little VW beetle, but the four of us and our luggage, which I was prepared to abandon, fit into it nicely. Our biggest strategic problem was that we were on the wrong side of the Vltava River. We had to cross a bridge, but all of the bridges were heavily guarded by tanks, gun emplacements, and young soldiers with assault rifles. Except for military vehicles, the traffic was not crossing. Nothing ventured, nothing gained. We drove to one guard position and asked, in our best mixture of Russian, English, and sign language, if we could cross. The soldier on the driver's side of the car, after pointing his weapon at us and eyeing the passengers,

disinterestedly waved us through. The soldier on the other side of the beetle seemed to disagree. We decided to go ahead and leave the soldiers to "talk it out." It was an anxious moment, but we drove across the bridge and never looked back. The soldiers on the far end of the bridge thought that if it was okay to let us on the bridge, it was certainly okay to let us off. We drove through the guard position at a modest speed, looking for street signs to point us on our way to Rudna. There were none. The Czechs had removed most of the street signs and highway signs to cause problems for the Russians.

Actually we found the right road to Rudna with little difficulty just by counting blocks on our city map. We were making good progress when we encountered a 10-car traffic jam. Two tanks were blocking the road, and a tank commander was motioning for the cars to turn around and go back. He was not allowing anyone to pass. We didn't know what to do. We were off of our map, but we had noticed a side road a mile back and decided to try taking it in hopes of going around the roadblock. Since the road didn't go very far, we had to turn around. Then we noticed a Czech on a motorcycle beside the road. He gestured for us to cross a cultivated field. We followed the tracks in the field. At one point we almost got stuck, but finally we came out of the woods onto the road to Rudna about a half mile beyond the roadblock.

When we arrived at Rudna, only five cars were there, all Americans and Brits. The diplomatic representative had not yet arrived. I purchased some candy bars and food at a small store in case we were stranded in the countryside for a long time. The embassy staff member arrived, accompanied by a truck carrying a load of full five-gallon gasoline cans. We gassed up all the cars, which by then numbered around 50, and drove toward West Germany via Pilzen. We occupied ourselves by counting tanks and armored vehicles, which in this sector were mostly East German. We crossed the border without incident. Fortunately for us, the invaders were anxious to have all foreigners leave the country. Warner, who was attending the same congress with his wife, was staying in another hotel

across town and left Czechoslovakia on a special train to Vienna. It was my first, last, and only trip to visit the Czechoslovakian tektites.

Although tektites do not come from the Moon, some meteorites should. There didn't seem to be anything wrong with the meteorite impact mechanism for providing lunar ejecta that would fall on the Earth. Clearly, tektites were not that ejecta, but pieces of the Moon could be expected to show up somewhere in the meteorite collections. Because the bulk density of the Moon is so low, only 3.34 grams per cubic centimeter, it cannot contain much very dense material, such as metallic nickel-iron. So, it seemed logical that the place to look for lunar fragments was among the less dense stony meteorites. Using NASA-MSC press releases to make people aware of the potential importance of previously unrecognized meteorites, I invited the public to send pieces of suspected meteorites to me for identification.[17]

It wasn't long before I received a fragment of a common type of stony meteorite from an area near Sweetwater, Texas. Recovering a previously unknown stony meteorite was a real thrill. When writing to a colleague at the Smithsonian Institution about another matter, I mentioned I had identified a new chondrite in West Texas and that I would send a slab for the Smithsonian collection after the specimen was cut. I received a terse reply ordering me to send the whole piece immediately. Folks at the Smithsonian were jealously guarding their turf as keepers of all government meteorite samples. Their orders led to an exchange of letters between the head of the Smithsonian and the NASA administrator. Ultimately a compromise enabled us to send whatever meteorite samples we had that were government property to the Smithsonian, but only after we completed our research with them. Thereafter, I was careful to acquire specimens privately whenever it was feasible or desirable.

After a classroom lecture on meteorites, Clanton, Foss, and I

[17]The invitation stands. Please send me a walnut-sized sample of any suspected meteorite you come across, and I will identify it and return it to you. Send to Bert King, Department of Geosciences, University of Houston, Houston, Texas 77204-5503.

were talking with astronaut Rusty Schweickart and mentioned we were going to New York for a technical meeting. Schweickart, who had been selected for the crew of Apollo 9, checked his pocket calender and noted he would be on Long Island at Grumman to check out his Lunar Module (LM) at about the same time. He gave us a number where we could reach him at Grumman and invited us to stop by if we had the chance.

The meeting ran late. We ate a hamburger for dinner and called Schweickart, hoping he might be working late. We located him through Grumman's paging system, and he gave us directions to the facility. He notified plant security we were coming, and we met him at the entrance to a large hangar-like building. Within the large, clean area were several fledgling LMs in various states of fabrication. I felt as if I had stumbled into the nesting place of the Valkries! Schweickart explained the LM electrical systems and other LM systems. After an hour, we left him to more serious work. As we walked out into the parking lot, the huge, yellow, nearly full Moon illuminated the night sky. The Moon appeared close enough to touch, but I knew it was more than a quarter million miles away. I couldn't imagine landing on the Moon in one of the tiny spacecraft I had just seen. But that was exactly what we would soon attempt.

I continued to work with meteorites. I chased fireballs and recent falls, which was sometimes frustrating and sometimes fun, but rarely resulted in a recovery.

A group of meteorites called "basaltic achondrites" appeared to be the best candidates for lunar meteorites derived from the lunar maria.[18] These are rare meteorites with igneous volcanic textures similar to terrestrial basalts.

In December 1968, Apollo 8 took Borman, Lovell, and Anders away from the Earth, around the Moon, and back again by Christmas. Other missions were soon to follow.

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[18]This idea, which was originally suggested by Cal Tech graduate student Mike Duke and his professor, Dr. Lee Silver, proved to be incorrect. Lunar meteorites were recognized in the meteorite collections from the Antarctic ice, but only years after the Apollo missions were over.

While unsuccessfully searching for a meteorite fall close to Crosby, Texas, I heard on the car radio about a very bright fireball witnessed in southern New Mexico, Texas, and northern Mexico. I returned to my office and asked my secretary, who was fluent in Spanish, to place some phone calls for me. I first contacted a newspaper editor in Chihuahua City. We had a lengthy conversation about the phenomena accompanying the meteorite fall but no specimens had fallen near Chihuahua City. Finally, I asked him the right question: "Do you know anyone who has any pieces of the meteorite?" "Oh yes," he said, and suggested that I call the newspaper editor in Hidalgo del Parral, much further to the south. My secretary located Sr. Ruben Rocha Chavez, editor of *Correo del Parral.* He recounted how a brilliant fireball had broken apart with a loud explosion in the middle of the night and had showered fragments over a large area near Parral. Chavez had several pieces of the meteorite on his desk and described them to me. There was no doubt—he had fragments of a freshly fallen stony meteorite! He invited me to visit Parral to see his pieces and to collect specimens. I thanked him for the information and his invitation and told him I would be there as soon as possible.

A quick check of airline schedules showed it was not going to be easy to get to Parral. I could fly to El Paso, but that was still more than three hundred miles north of Parral. It was the fastest way, however. My secretary promised to cover me with paperwork. I stopped by my house for a few clothes and headed for the airport. The plane took off on time, but, as luck would have it, a faulty landing gear indicator light grounded us in San Antonio for five hours while it was replaced. By the time I arrived in El Paso it was already dark. I picked up a rental car, cleared through customs, and drove south. It was important to recover pieces of the meteorite right away in order to measure their short half-life radioactivities. This would be great practice for the Radiation Counting Laboratory of the LRL. The Mexican highways were difficult to negotiate in the dark. The best technique was to follow a hundred yards behind a car with Mexican license plates. Some of the drivers were going 80

miles per hour, and when I saw brake lights or a cloud of dust, I knew the driver had spotted a burro on the highway. I arrived in Parral just after dawn. I checked into a hotel, washed up, drank some strong coffee, ate eggs and tortillas, and went to look for the newspaper office. I was waiting when the editor arrived.

I was astonished when I saw the two big meteorite pieces on the editor's desk. One weighed more than 30 pounds. The greatest surprise was the meteorite type—a rare carbonaceous chondrite. Chondrites are stony meteorites that contain chondrules, small spheres of silicate of disputed origin. Carbonaceous chondrites are chondrites that contain abundant carbon and organic compounds. While I was standing in Chavez' office, the telephone rang. The editor handed the receiver to me. It was a colleague from the Smithsonian who wanted information about the meteorite. He had called my Houston office, where my secretary gave him the number of the newspaper office. I told him what little I knew. I asked the editor about his plans for the two specimens on his desk. He said they were reserved for the National Museum. I agreed this was perfectly appropriate, but I was eager to recover some additional specimens.

The editor said I must visit the local municipal president or mayor. I was going to be treated as an official NASA representative. The mayor, Sr. Carlos Franco, was extremely gracious, and though my Spanish was meager and he spoke little English, we had an amiable meeting. I explained, through the editor as translator, how scientifically important meteorites are in general and that this particular one was a very rare type. Sr. Franco was eager to help me, and he assigned me one of his policemen and an official car for as long as I needed them.

We drove to places where specimens had been found. Recovering additional specimens proved to be easy. Everyone had small pieces of the meteorite, but I wanted some larger ones. I purchased these from the local people, with the policeman acting as interpreter and handling the negotiations. We documented several sites where specimens had been found. The stones had showered over a large area. One large stone had missed the post office in Pueblito de

Allende by only 30 feet. Meteorites normally are named after the nearest post office. This one almost named itself. We listened to many tales of the fireball, its direction of travel, the loud claps of thunder, stones falling everywhere, and people running to the church in the middle of the night. I picked up 13 pieces of the meteorite (Photos 43–44), including two large ones—enough samples for the time being.

By late afternoon, the day began to seem very long. I had not slept in 30 hours, and I still had to drive back to El Paso. We stopped at a little cantina, and I bought drinks for the meteorite party—the policeman, a local engineer who had been very helpful, and the Mexican reporters who had followed us all day. I bid them *adios* and hoped to make it to El Paso before nightfall. I pinched my arms and bit the back of my hand to stay awake. I arrived in El Paso after dark and entered U.S. Customs. I was met by a young customs agent who had taken a course in geology and wanted to know about the rocks I had. I finally reached the airport, turned in the

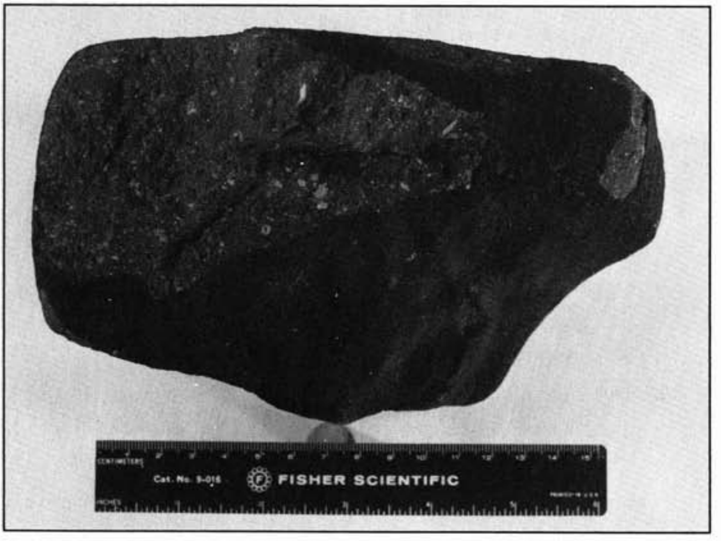

Photo 43. A piece of the Allende meteorite showing typical thin black fusion crust (ablation skin) and a broken surface. (Photograph by the author)

rental car, and inquired if anyone from Washington had made car reservations. Two of my Smithsonian friends had reserved cars, so I left them a long note telling them who to see and where to go to recover additional meteorites. I called Houston and told them to get the lab ready. I dozed for several hours in the airport until boarding time and then slept all the way to Houston.

One hundred and one hours after the fall we were gathering

Photo 44. Sawed slab of the Allende meteorite showing sections through numerous chondrules. Length of field of view approximately four centimeters. (Photograph by the author)

data on a piece of the Allende meteorite in the LRL low-background gamma-ray counter.[19] The Allende meteorite proved to be a "gold mine" of meteoritical science. We distributed many pieces to various investigators, using the procedure as a dress rehearsal for the lunar sample analyses. My own work with Allende would have to wait. It was too close to arrival time of the first lunar sample, and a lot of work remained to be done at the LRL. Allende became the best known and most studied meteorite in history.

In March 1969, the Apollo 9 crew—McDivitt, Scott, and Schweickart—flew a mission in Earth orbit. Schweickart didn't get to take his LM to the Moon, but the mission provided invaluable engineering data.

I was unexpectedly given a two-hour time slot with the Apollo 11 crew for a refresher in rocks, minerals, and meteorites. I borrowed some rare specimens for the session from Dr. Carleton Moore of the Center for Meteorite Studies at Arizona State University. The Apollo 11 crew wanted to know about tektites. Was there any possibility the tektites came from the Moon? I answered "no," then gave them a brief explanation and history of the topic.

The crew also wanted practical advice on sample collecting. Was it better to get one extremely well-documented sample or several undocumented samples? For the first landing, no one would complain if the astronauts collected several samples with minimal documentation. Rock scientists would be particularly pleased if the crew brought samples of different rock types. Collecting rocks that looked different from each other was important, if possible.

Apollo 10 carried out most of the mission to the Moon except for the actual landing. The crew of Stafford, Young, and Cernan were launched in mid-May and enjoyed an extremely successful flight. Apollo 11 was next!

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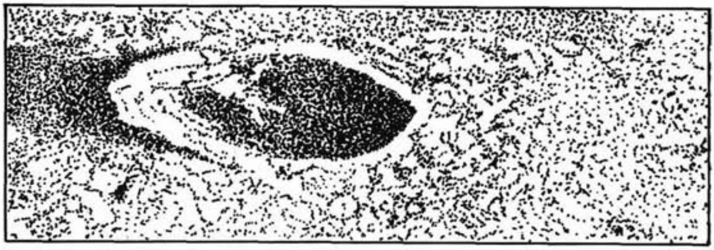
[19]E. A. King, E. Schonfeld, K. A. Richardson, and J. S. Eldridge, "Meteorite Fall at Pueblito de Allende, Chihuahua, Mexico: Preliminary Information," *Science*, vol. 163 (1969), 928–929. See also, E. A. King, Jr., "The Largest Stony Meteorite," *Pacific Discovery*, vol. 25, no. 1 (1972), 12–14.



V. First Lunar Landing

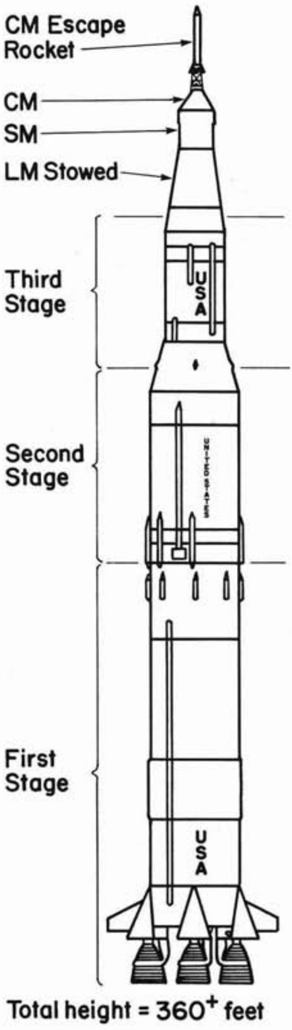
Based on the best guesses of various engineering managers, rumors around the space center were that Apollo 12 would be the first attempt to land on the Moon. After the extremely successful flights of Apollo missions 8, 9 and 10, however, "word" filtered down that the first lunar landing attempt might come on Apollo 11 if the mission went well. We notified some of our investigators to get their labs ready. One of the investigators I telephoned dropped the receiver when I told him, and I heard him shouting to his associates and lab techs, "We have to be ready for Apollo 11!" Our "countdown" calendar inside the front door of the LRL was a sobering sight. Each day's end meant we had one less day to get ready to receive lunar samples.

The new schedule for the lunar landing attempt caught the Soviet Union unprepared. Only three days before the Apollo 11 launch, the Russians launched a hastily assembled Luna 15 spacecraft designed to land on the Moon and return a small lunar sample. I have only rarely wished anyone ill luck with a space mission, but I was relieved to learn that the Russian spacecraft had crashed into the Moon. We would have been greatly disappointed if the Russian mission succeeded in returning a lunar sample to Earth before the Apollo program.

The southern edge of Mare Tranquillitatis was selected as the Apollo 11 landing site for two main reasons: 1) the area was relatively smooth and 2) the Surveyor V spacecraft landed there in September 1967. Surveyor V carried an alpha backscatter device to analyze the lunar surface. The analysis indicated the surface was basaltic, but a final refinement of the data, published by Dr. Tony Turkevich and his team just before the Apollo 11 launch, indicated the rocks were titanium-rich.[20] Turkevich's report was not anticipated. Many scientists ignored it, knowing that soon we would have samples for terrestrial laboratory analysis. Others privately expressed the opinion that the analysis was in error; after all, no theory of the Moon required that the rocks be rich in titanium. Later analyses of returned samples proved Turkevich and his co-workers had been exactly correct.

The immense stack of Apollo 11 hardware now dominated the Cape (Figures 4–6). The complete Saturn 5 assembly towered more than 360 feet above the launch pad. On July 16, 1969, at 8:32 a.m. EST, Apollo 11 lifted off the launch pad and began what geologists called "the big field trip in the sky." The check-out in Earth orbit, translunar injection, transposition and docking, spacecraft ejection, and translunar coast were virtually identical to those of Apollo 10. All systems were "go." Only one mid-course correction was required.

[20]A. L. Turkevich, E. J. Franzgrote, and J. H. Patterson, "Chemical Composition of the Lunar Surface in Mare Tranquillitatis," *Science*, vol. 165 (1969), 277–279.



Apollo Saturn 5

Figure 4. Scale drawing of the Apollo Saturn 5 launch stack showing the three rocket stages and the launch positions of the Command Module (CM), Service Module (SM), and the Lunar Module (LM). The first stage is composed of five F-1 engines which burn 4.6 million pounds of kerosene and liquid oxygen in 160 seconds to produce a combined thrust of 7.5 million pounds! The second stage burns liquid hydrogen and liquid oxygen in five J-2 engines for 6.5 minutes to produce a combined thrust of more than a million pounds. The third stage propulsion unit is a single J-2 engine that produces the final thrust required to achieve Earth parking orbit and another burn to gain trans-lunar injection. On top of this mighty stack of rocket engines is the LM, with its legs neatly folded under a large, smooth fairing; the SM; and the CM. The uppermost unit is a launch emergency escape system, including a modest rocket that could take the CM clear of a potential launch accident.

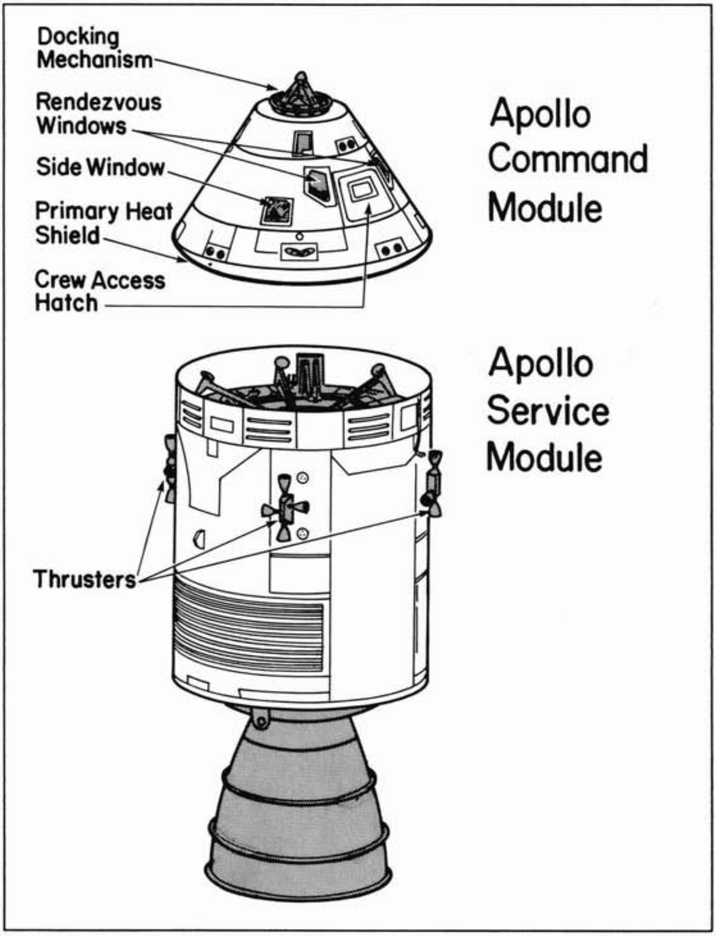


Figure 5. After trans-lunar insertion is accomplished with the third stage J-2 engine, the Command and Service Modules detach from the fairing covering the Lunar Module, turn around, dock with the hatch on top of the Lunar Module ascent stage, and pull the whole LM out of the expended third stage. The CM is the 12-foot, 10-inch diameter spacecraft with a heat shield for re-entry and all of the control panels. It houses the three-man crew except during lunar orbit, when the normal crew numbers only one. The SM contains the main propulsion engine for the CM and the SM. Together, the CM and SM are designated as the CSM until the SM is detached and abandoned just prior to re-entry. The SM is 24 feet, seven inches long and is the same diameter as the CM, so they fit together neatly.

The spacecraft braked into lunar orbit at approximately 76 hours ground elapsed time (g.e.t.), and a routine circularization of the orbit was made two revolutions later.[21] The check-out of the Lunar Module (LM) was nominal, and the crew took a planned rest period. Armstrong and Aldrin finally entered the LM. The LM and the Command and Service Module (CSM) undocked, and the descent to the lunar surface began at about 101.5 hours g.e.t. During powered descent to the lunar surface, the crew had to assume

[21]For a technical summary of the Apollo 11 mission activities, see "NASA Apollo 11 Mission Report," NASA SP-238 (1971). Also, see a less technical review of the Apollo missions by S. F. Cooper, Jr., *Apollo on the Moon* (New York: Dial Press, 1969).

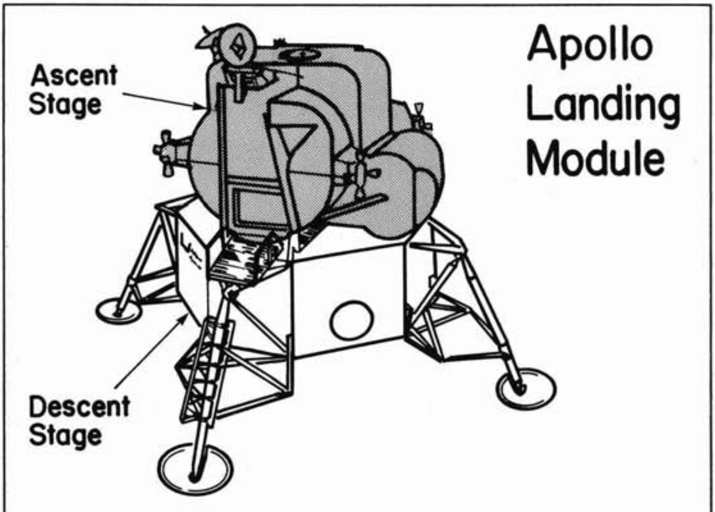


Figure 6. Apollo Lunar Landing Module (LM). The LM is divided into an ascent stage (shaded) and a descent stage (unshaded). The descent stage provides the liquid rocket engine for descent to the lunar surface from lunar orbit. With legs extended, the LM descent stage has a maximum diameter of 31 feet.The descent stage also serves as the launch platform for the ascent stage. The ascent stage contains the two-man crew and controls for the entire LM, as well as the small solid-fuel rocket for liftoff of the ascent stage from the lunar surface back to lunar orbit.

manual control of the descent path when it became clear that the automated flight path would place them in a boulder field near a fresh crater. This maneuver to avoid boulders took two and a half minutes and resulted in a down range translation of approximately 1,100 feet. The maneuver was costly in terms of descent stage fuel, and the Eagle touched down at Tranquility Base (Photo 45) with precious little descent stage fuel left! Nonetheless, the landing was successful.

After check-out of all LM systems and a meal, the crew decided to perform their Extra-Vehicular Activity (EVA) earlier than originally planned. Mission Commander Armstrong egressed first through the forward hatch and pulled a lanyard that deployed the Modularized Equipment Storage Assembly (MESA). Through the eye of a wide-angle television camera lens mounted on the MESA, we saw Armstrong take the first long step onto the lunar surface on July 20. We breathed a sigh of relief that the MESA deployed as it was supposed to, because the two rock boxes and most of the sample collection tools and bags were stored there.

The highest priority science activity was the collection of the "contingency sample." Armstrong had been provided with an extendable handle to hold a small teflon bag that enabled him to scoop up a few small rocks and store them in a pocket on his pressure suit—a small measure taken just to hedge our bets. If something went wrong and the crew had to leave the lunar surface prematurely, we wanted to be certain to have at least a small sample of Moon rocks. Armstrong accomplished the contingency sample collection and storage within his first minutes on the Moon, even before Aldrin egressed.

The most important scientific part of the mission was just beginning when President Nixon called to talk to the crew. The conversation lasted only two minutes, but it seemed like forever. Planting the U.S. flag was an activity we viewed with mixed emotions. We were proud to see "Old Glory" on the Moon, but the astronauts had a lot of important work to do. The crew soon got to it, though, and three major experiments were efficiently deployed: a passive seis-

mometer, the laser ranging retroreflector, and a solar-wind composition experiment. The seismometer would detect "moonquakes" and meteoroid impacts and provide us with information on the internal structure and activity of the Moon. The laser ranging retroreflector was an array of optical corner reflectors that could reflect an incident light beam back exactly along its incident path,

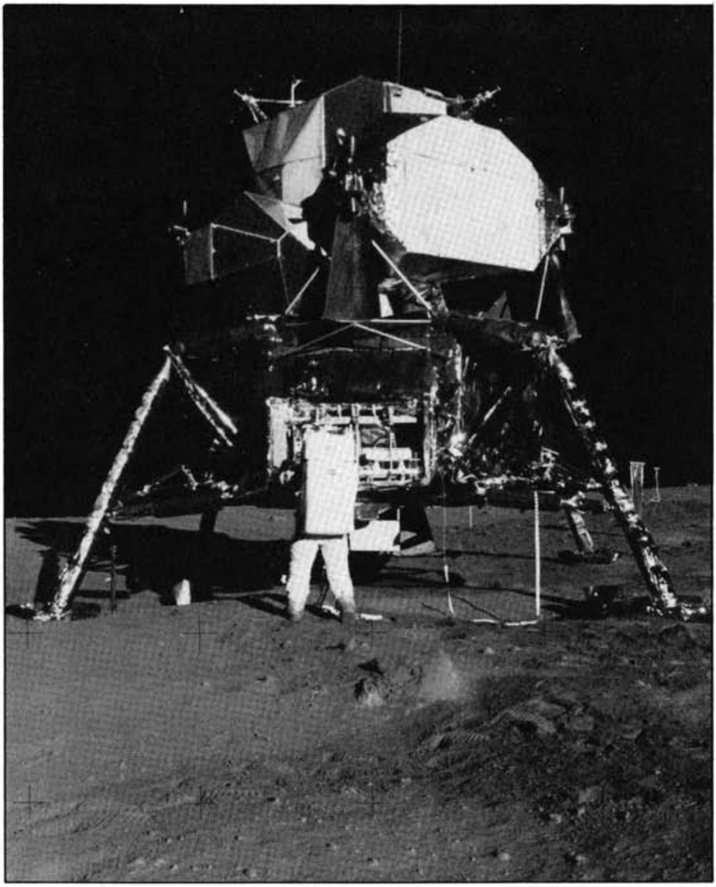


Photo 45. Tranquility Base. Astronaut Buzz Aldrin is unloading some of the lunar surface experiment apparatus for deployment. Note the lack of topography and smooth nature of the surface. (NASA photograph AS11-40-5927)

making it possible to determine exactly the distance from the light source to the reflector by precisely measuring the time it takes the light beam to make the two-way trip. The purpose of the solar-wind experiment was to collect solar ions implanted into clean aluminum foil—possible on the Moon because the surface is neither protected by an atmosphere nor a strong magnetic field. We referred to the solar-wind experiment as the "Swiss flag" because it was deployed like an aluminum window shade on a pole stabbed into the surface and the investigator was Dr. Johannes Geiss from Bern.

Our primary concern was for the astronauts to collect the main samples. Two aluminum rock sample boxes were stored on the MESA. The first box was called the "bulk sample" and was filled with the immediately available surface material. Collection of the bulk sample took more time than planned because the MESA was in a shadow which made sample collection more difficult. Armstrong remarked that using the sample scoop posed a problem because it was difficult to scoop material from the surface without throwing the sample out of the scoop. He tried to get at least one hard rock in each scoop and was careful to collect some samples away from the descent stage exhaust plume and propellant contamination. The box was sealed for later transfer to the LM ascent stage.

Two core tube samples were collected, although the crew had problems getting the core tubes to penetrate into the lunar soil more than about six inches even though a hammer was used to drive the tubes. The second rock box was designated as the "documented" sample, where the rocks on the surface were photographed before collection. Time ran short, however, and few samples were actually documented. Armstrong selected as wide a variety of rocks as possible for the second box during the remaining time. The second rock box was then vacuum sealed, after including the rolled-up aluminum foil from the solar-wind experiment, and was prepared for transfer to the LM ascent stage.

Meanwhile, Mike Collins continued monitoring the CSM in lunar orbit. Although he attempted to locate the LM on the lunar

surface during each pass, Collins was never able to see it. He coordinated his sleep periods with those of the surface crew so that radio silence could be maintained.

On the ground in Houston, the Field Geology Experiment Team were keeping track as well as they could of where samples were collected and any other significant observations about the landing site. In the LRL, we were trying to estimate the number of rocks, sizes of various samples, and other sample data that would help us handle the returned rock boxes and their valuable cargo.

The rock boxes and film magazines were transferred into the LM ascent stage. A number of housekeeping duties were performed, and excess gear was thrown out the front hatch. The rock boxes were securely stowed into racks by metal pins that extended when the box handle was twisted. The lunar surface exploration had lasted two hours and 14 minutes. Safely back in the LM ascent stage, the crew took a well-earned though unsuccessful eight-hour rest period. Noise, lighting, and cold temperatures made sleep difficult. Aldrin estimated that he slept fitfully for perhaps two hours. Armstrong did not sleep at all.

Preparing the LM ascent stage for launch was the next task. The solid rocket motor for the ascent stage had to work. No backup existed. The platform was aligned, the navigation program entered, and various instrument checks made. The pyrotechnic bolts securing the ascent stage to the descent stage were blown with a loud noise, but the crew could not hear the ignition of the ascent stage rocket motor. The motor and the guidance system worked flawlessly. All three crewmen were once again in lunar orbit, though still in different spacecraft. The CSM completed a docking maneuver with the LM ascent stage approximately four and a half hours after ascent stage launch. The short tunnel between the ascent stage and the CSM was cleared, and the items designated for transfer to the CSM were cleaned with a vacuum brush and stowed in bags for the transfer. The two rock boxes were stowed in prime space for the trip to Earth. The LM ascent stage was jettisoned in lunar orbit. At 135.5 hours g.e.t., the CSM engine fired and sent the

crew back into transearth trajectory. The main propulsion systems had completed their jobs. Only one small midcourse correction was required during transearth coast, and this was accomplished using the small reaction control system thrusters.

The service module separated from the command module 15 minutes before reaching the entry altitude of 400,000 feet. Thunderstorms in the primary recovery area necessitated a change of 215 miles down range of the landing point. Entry was normal, and splashdown occurred in the Pacific Ocean at 195.25 hours g.e.t. on July 24. In spite of our worst fears, hundreds of thousands of components performed perfectly or within tolerable limits. The complexity of the mission was enormous. Second-by-second mission timelines were unbelievably detailed, yet the whole event played like a well-rehearsed symphony. It was perhaps one of the greatest accomplishments of our civilization. Shouts of joy and victory rang out all over the space center. Splashdown parties began instantly.

A flotation collar was fitted to the spacecraft and inflated, the hatch was opened, and the crew egressed in uncomfortably hot biological isolation garments (Photo 46). The hatch of the Command

Photo 46. Apollo 11 crew taking water egress training in the Gulf of Mexico. Assisted by recovery personnel (standing and in water), he crew of Armstrong, Aldrin, and Collins have donned biological isolation garments and egressed from the boilerplate Command Module into the adjacent rubber raft. (NASA photograph S-69-34881)

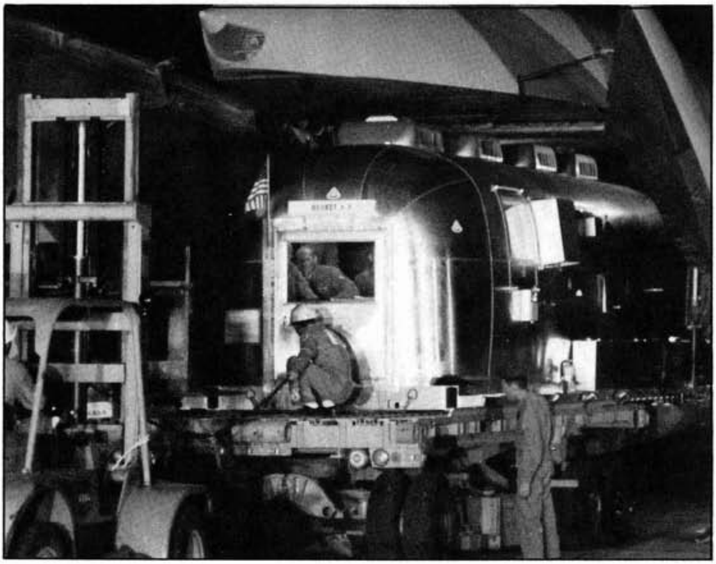


Photo 47. The Apollo 11 crew inside the Mobile Quarantine Facility (MQF) arriving at Ellington Air Force Base, Houston. A large crowd gathered to welcome the crew. (NASA photograph S-69-40152)

Module was again closed. About an hour after splashdown, the crew boarded the U.S.S. *Hornet*. They entered the Mobile Quarantine Facility (MQF) where they would have to remain until their arrival at the LRL (Photo 47). The Command Module was lifted aboard the *Hornet* and attached to the MQF by a plastic transfer tunnel. The hatch of the spacecraft was reopened, and the rock boxes were removed via the transfer tunnel into the MQF. There, the rock boxes were sealed in plastic bags, the surfaces of the bags sterilized, and the bagged boxes passed out of the MQF for rapid transfer to the LRL. Our crew was safely back on the Earth, and approximately 47 pounds of lunar samples were on their way to the scientists at the LRL. What could be better than that?

I broke out several bottles of Pol Roger champagne that I had chilled earlier, just in case. Booze and party supplies began to appear everywhere. NASA splashdown parties are legendary for their

enthusiasm and endurance. But even among the memories of the most experienced party animals, this celebration was the most unforgettable. Parties raged in offices, local bars, hotels, civic centers, public parks, private residences, sailboats, and parking lots. The strain was over. The deed was done. We could kick back and bask in the reflected glory of the mission. Pockets of determined celebration lasted for three days. I dropped in and out of several parties, but I didn't have much time. We had to make final preparations at the LRL for the samples' arrival.

VI. The Lunar Samples

The lunar samples were on board the U.S.S. *Hornet,* and we were eager to get additional information on the quantity and types of samples. The crew had been very busy while on the Moon and had not been too talkative about matters that would help us prepare for sample processing and preliminary examination. We decided to send a message to the *Hornet:*

MSC HOUSTON TEXAS — PRIORITY — UNCLASSIFIED

Answers to the first six questions are required prior to arrival of the samples. Please ask the crew the following questions.

1. Approximate amount of fine-sized sample material in documented (second) box
2. Ratio of rocks to fine-sized material in bulk (first) box

3. What is the estimated number of rocks in the documented box?
4. Approximate number of different rock types collected?
5. Are there any samples that appear friable or weakly coherent? If so, approximately how many?
6. Did any samples show color or albedo differences that will enable us to tell tops from bottoms?

Also, please ensure that the documented sample box (second box collected) returns on the first aircraft.

Richard S. Johnston, Special Assistant to the Director
Elbert A. King, Jr., Curator
July 24, 1969, 3:50 p.m.

Their reply came promptly:

---

1. Very little, pretty much hard rock
2. Approximately 60 percent fine-sized material
3. Twenty rocks in sample, average one earth pound
4. Approximately six rock types
5. Somewhere packed, doubtful if still in rock form
6. Some lighter on top and darker on bottom

With great euphoria we set up tools and containers in the high vacuum glove chamber accordingly. Arrival at the LRL of the lunar samples was only hours away.

We had taken great precautions to ensure the safety and integrity of the lunar samples once they arrived on Earth. Besides the quarantine precautions, the rock boxes were placed in crash-proof boxes. At 05:15 Greenwich mean time, July 25, an aircraft carrying the documented sample box was launched from the *Hornet*. It was bound for Johnston Island, where another long-range aircraft would carry the box to Houston. Six hours and 30 minutes later, the *Hornet* launched another aircraft transporting the bulk sample box

toward Hickam Air Force Base, Hawaii, with the same final destination for the samples.

Someone made a bad joke that it would be a shame if the samples got almost to the LRL but never made it. How could this happen? Maybe a radical group of "hippies" would use the occasion to draw attention to their cause by mounting a demonstration or protest involving the samples. It was the sixties. All kinds of crazy things were happening. Students burned flags and blew up computers. Under the circumstances, I felt extremely paranoid. Only a weak link connected the chain of sample security beginning with the landing of the samples at Ellington. Once the samples were on the base they would most likely be safe. However, a long stretch of Old Galveston Highway and NASA Road One left the samples vulnerable to sabotage before arriving at the space center. I decided the only prudent thing to do was to personally escort the samples. I went home and dropped six fresh rounds into the cylinder of my long-barreled Smith & Wesson .357 magnum, wrapped it in a bath towel, and stuck it under the front seat of my '63 Plymouth Valiant. Of course, probably nothing would happen, but if it did, someone would quickly know I meant business.

The first aircraft carrying the documented sample box landed (with one engine out!) at Ellington more or less on time. I parked where I could see everything on the edge of the runway and watched the transfer of the rock box container from the aircraft to a NASA vehicle (Photo 48). As I imagined, the scene was disorganized and uncontrolled. I followed as the NASA vehicle pulled away and stayed closely behind all the way to the space center. A couple of other cars, one of which was driven by a NASA security officer I knew, jockeyed for position in the column. The NASA security man honked and waved me off. I just honked back, waved, and smiled. The trip from Ellington to MSC proved uneventful, and the documented rock box was admitted to the LRL. The bulk sample box arrived seven hours later. The long-awaited lunar samples were "in the bag!"

A lengthy procedure was necessary in order to move the first

rock box into the high vacuum glove chamber where it would be opened. The anticipation was intense. We believed a glimpse of the samples would reveal before our eyes the hidden secrets of the Moon. Four science observer members of the Preliminary Examination Team (PET) waited at their stations on the vacuum chamber when the lid of the documented sample box was popped open. Frondel and I were together on the glove operator's side of the vacuum chamber, and two colleagues shared the other side. After the packing mesh was pulled aside and the foil from the solar wind experiment was moved out of the way, the glove operator came out of the gloves and stepped back, allowing us our first view of rocks from the moon. The sight was unimpressive. Dark lunar dust cov-

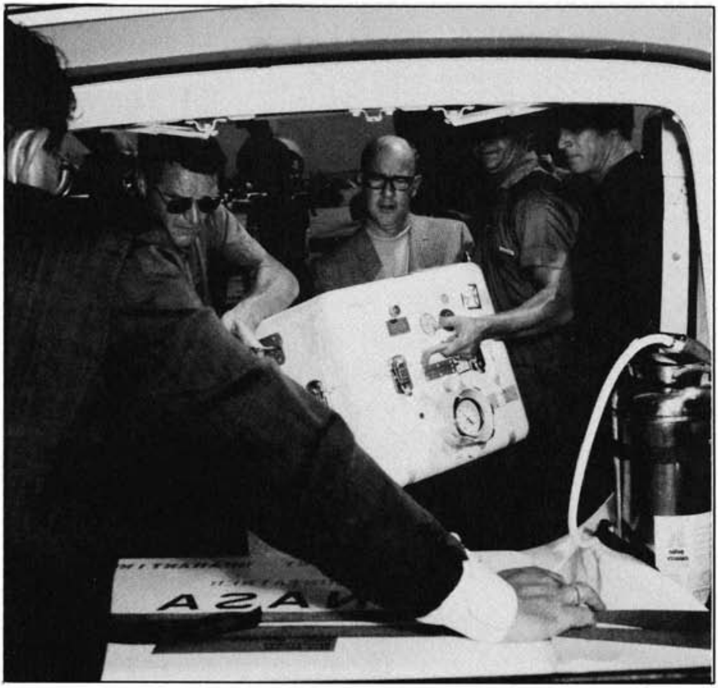


Photo 48. The first lunar rock box from the Apollo 11 mission arrives at Ellington Air Force Base, Houston, in its protective container and is loaded into a NASA vehicle for the short trip to the Lunar Receiving Laboratory. (NASA Photograph S-69-39967)

ered every rock so the true nature of the materials was not visible. One of our colleagues on the far side of the chamber said he could see a light-colored phenocryst (a crystal of larger size than the general matrix of the sample) in one of the samples—almost certainly feldspar and probably plagioclase. From our side of the chamber we could tell it was a flake of the alumina thermal coating from the outside of the box that had fallen on the rock when we opened the lid. We motioned over the top of the chamber for them to "cool it!"

The moment was truly history, but there was little we could observe or say.[22] We counted the rocks and described the size and shape of each piece, but they looked like lumps of charcoal in the bottom of a backyard barbecue grill. The pervasive dark lunar dust obscured everything for the time being.

Frondel became fascinated with the dark, opaque dust. He postulated the dust might be high in carbon, an idea Urey liked a great deal. Frondel stated this hypothesis at a press conference, but cautioned that his conjecture still had to be verified by analysis. His idea turned out to be incorrect.

The MQF, with the crew inside, arrived on July 28. The crew egressed into the LRL Crew Reception Area, which was spacious compared to the MQF. At least here the crew could enjoy some recreation, such as movies and reading material. I had left 10 years of back issues of *Playboy* magazine in the small library, each issue marked "Courtesy of your friendly neighborhood curator."

On July 30, the Command Module was delivered to the LRL, where it was scavenged for lunar dust after the quarantine period.

I participated in one of the technical debriefings of the crew, which took place across the biological barrier in a special room of the LRL Crew Reception Area (Photo 49). The crew seemed rested and happy, and we were all grinning from ear to ear. Little of scientific importance was gleaned from the debriefing. The science story was locked in the rocks, and we had plenty of those.

The rocks were individually cleaned and dusted, inside plastic

[22]For another account of the events of this time, see S. F. Cooper, Jr., *Moon Rocks* (New York: Dial Press, 1970).

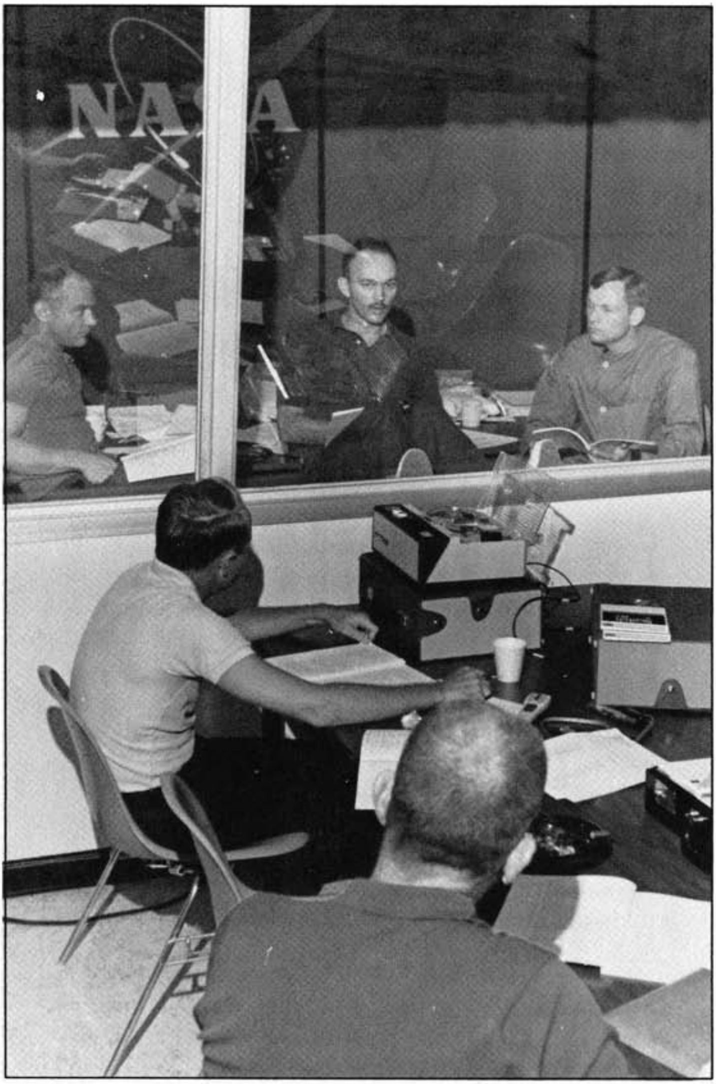


Photo 49. The Apollo 11 crew of (left to right) Buzz Aldrin, Mike Collins, and Neil Armstrong at their first post-flight debriefing in the Lunar Receiving Laboratory. The crew are isolated on one side of a biological barrier and the debriefing team on the other. Deke Slayton (foreground) and Lloyd Reeder (training coordinator) are shown on this side of the barrier. (NASA photograph S-69-40216)

bags in order to avoid losing any dust particles. Their true nature quickly became apparent (Photo 50). The large rocks were of two types. There were ordinary-looking fine-grained volcanic igneous rocks that appeared as fresh as if they had been erupted only yesterday. Also, there were breccias composed of many rock clasts and fine material that had somehow become lithified from crumbly to hard rocks (Photo 51). We hesitated to identify by eye the minerals

Photo 50. Fine-grained lunar basalt with numerous vesicles or gas bubbles collected on the Apollo 11 mission. (Sample 10022, NASA photograph S-69-45524)

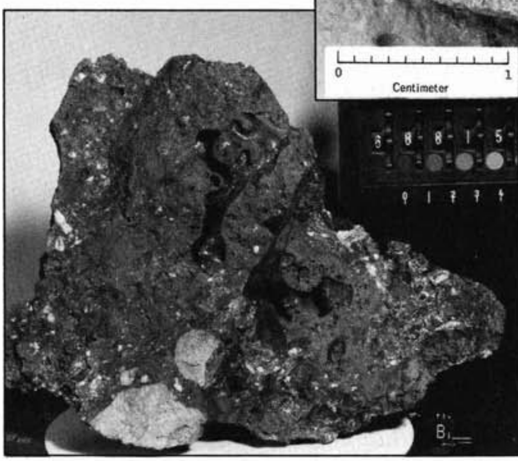


Photo 51. Glassy impact melt-breccia collected at the Apollo 16 landing site. This rock consists of many fragments with different grain sizes and textures held together by glassy material formed by meteoroid impact. Scale (right) is in centimeters. (NASA photograph S-72-37155)

in the igneous rocks because, as one PET member put it, "Remember, these rocks are from the Moon!" Observations were particularly difficult in the vacuum system (Photo 52) since the lighting was poor, the samples commonly were dusty, and there was little space

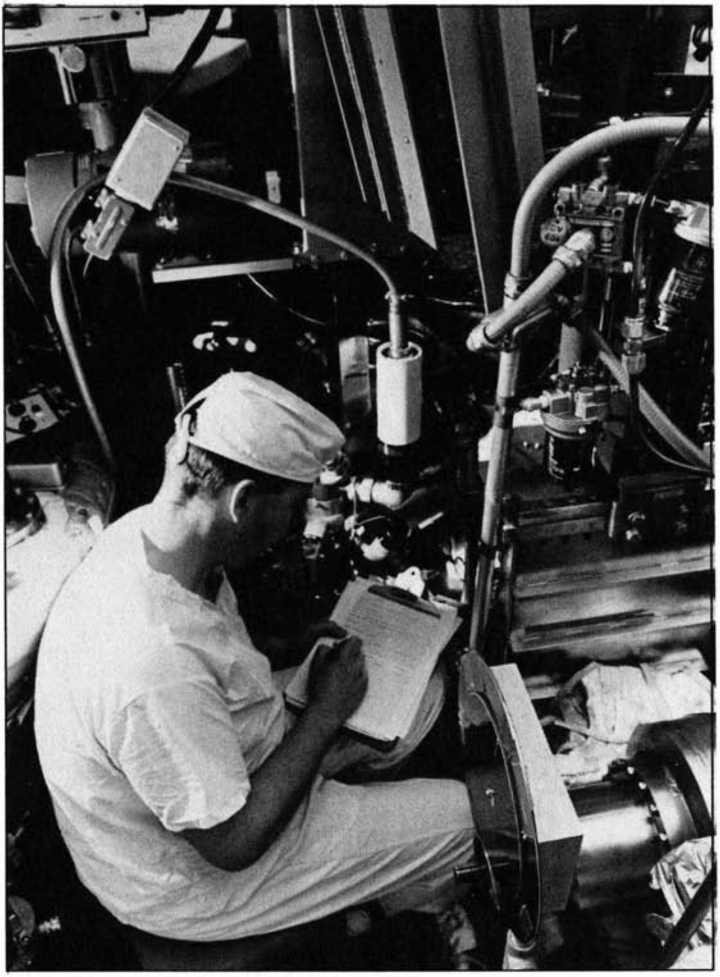


Photo 52. The author noting observations on an Apollo 11 rock sample at the main observer's port on the main vacuum system where the lunar samples were first opened. (NASA photograph S-69-29689)

for an observer. As each shift of PET came off duty, we discussed the new observations with LSAPT.

A curious feature observed on the first crystalline rock we examined was the presence of small glass-lined pits (Photo 53). The members of the PET generally agreed the pits were glass-lined micrometeoritic impact craters because the glass had splashed out over the rims. When this observation was reported to the Lunar Sample Analysis Planning Team (LSAPT) at the end of the shift, Shoemaker took strong exception to the interpretation and suggested the glass-lined cavities probably were vesicles or gas bubbles and would probably be found inside the rocks as well when samples were split. After all, there were no experimentally produced micrometeorite craters with glass linings. Discussion centered over the possibility that lunar microcraters might be produced by higher velocity meteoroids than the experimental ones, but Shoemaker was adamant. Soon we found the craters (which became informally known as "zap pits") on breccias and, of course, did not

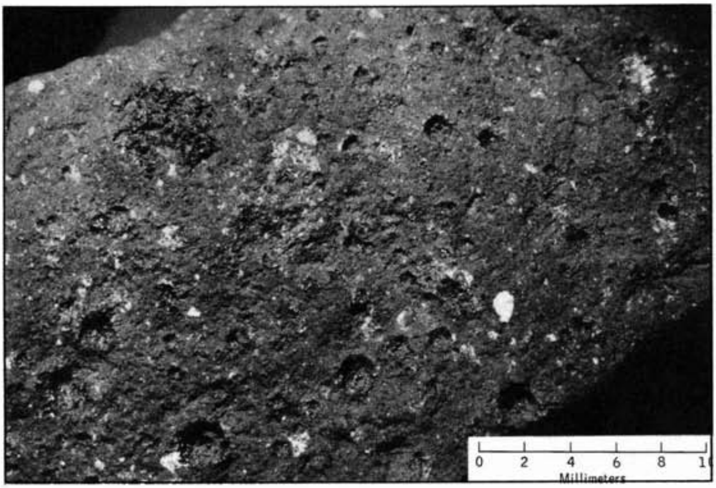


Photo 53. Apollo 11 breccia sample 10019, showing its surface with abundant micrometeoroid impact craters or "zap pits." These small glass-lined craters are abundant on many rocks from the lunar surface. (NASA photograph S-69-47905)

find them in the interiors of igneous samples. Shoemaker had to yield the point. Soon, our colleagues who had made experimental meteoroid impacts were making microcraters with glassy linings.

Chips were taken from a number of samples and passed to the Physical-Chemical Test Lab for the initial mineralogy, petrology, and geochemistry analysis and also to the Biological Test Labs for quarantine evaluation. We were especially pleased that no apparent sample reaction occurred with the dry nitrogen in the glove boxes. The PET, working slowly and moving cautiously, took a long time to derive a single positive mineral identification. We thought we had olivine, calcic plagioclase, and a pyroxene, but we had trouble working through the two-way barrier. The results were coming out very slowly (Photo 54). We opted to sterilize a small sample and work with it outside the biological barrier. I mounted a small yellow-green grain on a fiber and aligned it in an X-ray diffraction camera. A few hours later, analysis showed a pretty good

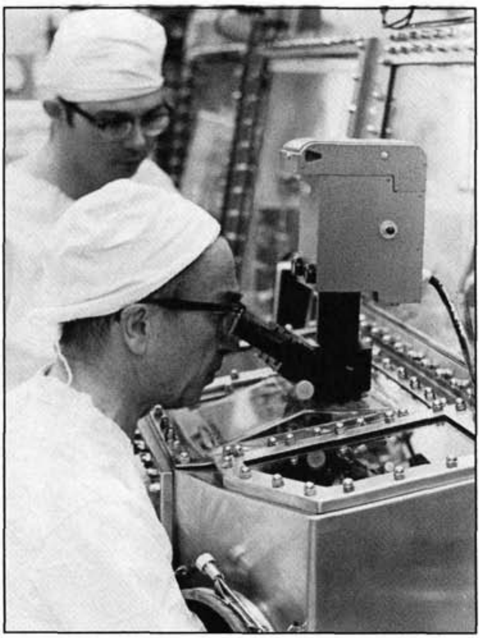


Photo 54. Prof. Clifford Frondel observing a lunar sample in a microscope whose optical path crosses the gas-tight, two-way biological barrier during the Apollo 11 preliminary examination and sample quarantine. Technician Dave Pettus at rear. (NASA photograph S-69-29682)

spotty diffraction pattern with 12 lines for olivine. By chance of orientation, however, the strongest line was missing. Once the first period of caution was over, data started coming out quickly. All the large crystalline rocks were basaltic, but the composition of one of the pyroxenes was something new. The breccias were composed mostly of basaltic rock fragments and glass.

Dr. Ross Taylor, of the PET, took an optical emission spectrograph shot of a lunar basalt. After seeing the bright white color of the "burn," Taylor remarked, "Whatever it is, it has a high titanium content." Several other samples displayed high titanium values. The common opaque mineral in the basalts from Tranquility Base was ilmenite, an iron-titanium oxide.

I opened up the Contingency Sample (Photo 55), which proved to be a marvelous miniature collection of lunar rocks and fine-sized particles. If this been our only sample brought back by Apollo 11, it still would have been a tremendous success.

Photo 55. The author unpacking and describing the contingency sample in the LRL during the Apollo 11 sample quarantine period. (NASA photograph S-69-40532)

In the samples of lunar dust and fine-sized material from the lunar "soil," we found a fascinating collection of small glass spheres (Photo 56) of different colors. These were products of micrometeoroids impacting the lunar surface, melting minerals and rocks, splashing the melt into near lunar space, and the solidified melt falling back to the surface. We would see these from all the lunar landings.

Warner had assembled a data storage and retrieval system for the lunar sample data. At the end of each shift, the new sample data was typed into the data system so it could be accessed by LSAPT or PET members outside the biological barrier. It was time to start compiling the data into a lunar sample catalog, which would be distributed to each sample investigator along with his sample.[23]

Armstrong, Aldrin, and Collins were released from quarantine on August 10, along with the Crew Reception Area staff. The PET also prepared a summary article documenting the results of the preliminary examination that would be published in a major journal of wide circulation.[24] Many of the PET members worked hard to prepare this initial article. The following 18 conclusions were drawn in this article:

1. The fabric and mineralogy of the rocks divide them into two genetic groups: (i) fine- and medium-grained crystalline rocks of igneous origin, probably originally deposited as lavaflows, dismembered, and redeposited as impact debris and (ii) breccias of complex history.
2. The crystalline rocks, as shown by their modal mineralogy and bulk chemistry, are different from any terrestrial rock and from meteorites.

[23]*NASA Lunar Sample Information Catalog, Apollo 11* (Lunar Receiving Laboratory, Manned Spacecraft Center, August 31, 1969). Only 400 copies of this catalog were printed, and it is now considered a collector's item.

[24]The Lunar Sample Preliminary Examination Team, "Preliminary Examination of Lunar Samples from Apollo 11," *Science*, vol. 165 (1969), 1211–1227.

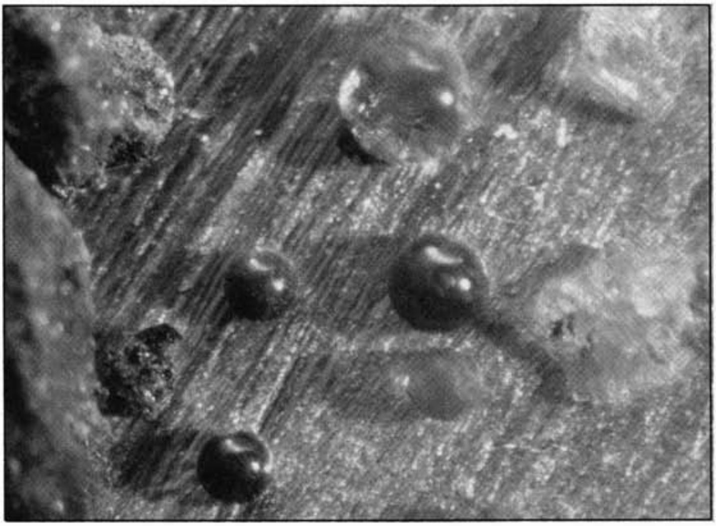


Photo 56. Glass spherules formed from the impacts of micrometeoroids into the lunar surface layer. Diameter of the largest spherule is approximately 0.5 mm. These are abundant in the fine-sized surface material at all landing sites. (NASA photograph S-69-45182)

3. Erosion has occurred on the lunar surface in view of the fact that most rocks are rounded and some have been exposed to a process which gives them a surface appearance similiar to sandblasted rocks. There is no evidence of erosion by surface water.
4. The probable presence of the mineral assemblage iron-troilite-ilmenite and the absence of any hydrated minerals suggest that the crystalline rocks were formed under extremely low partial pressures of oxygen, water, and sulfur (in the range of those in equilibrium with most meteorites).
5. The absence of secondary hydrated minerals suggests that there has been no surface water at Tranquility Base at any time since the rocks were exposed.
6. Evidence of shock or impact metamorphism is common in the rocks and fines.

7. All the rocks display glass-lined surface pits which may be caused by the impact of small particles.
8. The fine material and the breccia contain large amounts of all the noble gases, which have elemental and isotopic abundances almost certainly indicative of origin from the solar wind. The fact that interior samples of the breccias contain these gases implies that the samples were formed at the lunar surface from material previously exposed to the solar wind.
9. The potassium-argon isotopic measurements on igneous rocks show that they crystallized three billion to four billion years ago. The presence of nuclides produced by cosmic rays shows that the rocks have been within one meter of the surface for periods of 20 million to 160 million years.
10. The level of indigenous organic material capable of volatilization or pyrolysis, or both, appears to be extremely low (that is, considerably less than one part per million).
11. The chemical analyses of 23 lunar samples show that all rocks and fines are generally similar chemically.
12. The elemental constituents of lunar samples are the same as those found in terrestrial igneous rocks and meteorites. However, several significant differences in composition are apparent: (i) some refractory elements (for example, titanium and zirconium) are notably enriched and (ii) the alkali and some volatile elements are depleted.
13. Elements that are enriched in iron meteorites (that is, nickel, cobalt, and the platinum group) were not observed, or such elements are very low in abundance.
14. Of 12 radioactive species identified, two were cosmogenic radionuclides of short half-life, namely manganese 52 (5.7 days) and vanadium 48 (16.1 days).
15. Uranium and thorium concentrations lie near the typical values for terrestrial basalts; however, the ratio of potassium to uranium determined for lunar surface material is much lower than

such values determined for either terrestrial rocks or meteorites.

16. The high aluminum 26 concentration observed is consistent with the long exposure age to cosmic rays inferred from the rare-gas analysis.
17. No evidence of biological material has been found in the samples to date.
18. The lunar soil at the landing site is predominantly fine-grained, granular, slightly cohesive, and incompressible. Its hardness increases considerably at a depth of 15 centimeters. It is similar in appearance and behavior to the soil encountered at the Surveyor landing sites.

For several years, I had been teaching geology courses at night at the University of Houston. The Geology Department had one disgruntled faction. The department chairman resigned, a temporary chairman was elected, and I was asked to interview for the job. After thinking it over for a few days, I agreed to interview as a candidate for chairman. I was sure I could handle the administrative chores and felt I could lead the department to better performance. It also was clear that after the first lunar landing and sample return I would have to work in a university or research lab environment in order to have the opportunity to pursue serious research with the samples. I suggested I could join the Geology Department faculty after the Apollo 11 preliminary sample examination. I also wanted time to do my own research on the lunar samples. The university agreed. I gave my bosses several months' notice, but they waited until two weeks before I left to appoint my successor as curator. As it turned out, a number of scientists resigned from NASA at about the same time and, when interviewed, had similar criticisms of the space agency, complaining particularly about the lack of attention given to scientific goals.[25]

During the interim before the preliminary sample examination was complete, one of my big bosses called me. He had received an

[25]M. Mueller, "Trouble at NASA: Space Scientists Resign," *Science*, vol. 165 (1969), 776–777, 779.

inquiry from the White House staff, who wanted to know which lunar rocks we could provide as handsome presentation pieces for various dignitaries and politicians. My reply was "NONE!" "But President Nixon wants them," the big boss said. "Tell him he can't have them," I replied. I threatened to "blow the whistle" if they forced the issue while I was curator. How could we hand over precious scientific materials, for which men had risked their lives, as simple trophies? They got the message. I heard no more on the matter, but I had made a powerful enemy in the NASA chain of command because I had put him in a very awkward position.

The sample quarantine period was over, the *Lunar Sample Catalog* had been compiled and reproduced, and it was time to distribute the samples as recommended by LSAPT to approximately 144 principal investigators from 16 countries. The detailed work on the lunar samples was just beginning.

I was invited, together with a colleague, to bring a lunar sample and make a brief appearance on "CBS Evening News," which was anchored by Walter Cronkite. The spot was to be a live segment televised from a small studio atop a hotel across the road from the space center. The 12-foot-by-12-foot studio contained a mobile TV camera with a super wide-angle lens. We arrived at the studio at the appointed time, toting a large lunar sample carefully packaged in a gas-tight clear plastic container. We met the news reporter in charge of the segment, who told us we had exactly one and one-half minutes of live time. He reviewed with us the questions he would ask, and we briefly rehearsed our answers. We were both given earphones so we could hear the sound from the news show and the voice of a program director who was counting down to cue time. "Thirty seconds!" the director said. We were standing close together in front of the camera, with the lunar sample on a small table in front of us. "Twenty seconds!" the voiced boomed in our ear phones. When I looked at my colleague, he was visibly shaking. The newsman noticed, also, and began to look worse than my colleague. The voice in the earphone counted from 10 to "You're on!" as we heard Cronkite say, "And now, we go live to the Johnson Space

Center." The camera began wide, showing the three of us and the sample, but cut quickly to a close-up of the sample. The news reporter asked his questions, and I answered them while my colleague quickly disconnected his microphone and earphone and crawled away under the camera—a bit distracting, to say the least. Although my colleague had been on live TV and radio interviews a number of times, he got a bad case of "stage fright" this time. His exit was not visible on the transmitted image, but when the camera moved back to a wide view, one of the subjects was missing.

In November 1969, the annual meetings of the Geological Society of America (GSA) were held in Atlantic City, New Jersey. The Apollo 11 astronauts were invited to the meetings as honored guests and were awarded lifetime fellowships in the society at the annual banquet. I received an invitation to the GSA president's cocktail party, which preceded the banquet, though I wasn't sure why I had been invited. I brought my invitation, which was collected at the door, and entered a small ballroom with a couple of bars set up. At one end, a crowd of people was noisily trying to get close to Neil Armstrong. I could see from Armstrong's face that he was dazed and exhausted. Muehlburger, who was nearby, and I stepped into the crude line and worked our way toward Armstrong. When we finally reached Armstrong, he didn't recognize us for a few seconds. We reminded him who we were and told him to stand easy for awhile. We sent a friend to get him a drink and told him not to talk but to rest for a few minutes. Anxious autograph seekers were pushing against our backs, but we stood firm. After a few minutes the light came back into his eyes. He thanked us and assured us that he really could continue. We moved away, knowing that the hardest part of the lunar landing for Armstrong was dealing with the ensuing fame. The crowd didn't mean to be "pushy," but geologists so identified with a crew picking up rocks on the Moon that their enthusiasm got the best of them. I'm sure Armstrong was glad to see the cocktail party end and the banquet begin—at least he could rest a little at the head table. The remainder of the evening went as planned. Armstrong delivered a brief

speech and received a standing ovation. Feeling a little sad, I walked back to my room, hoping we would soon have another lunar crew so the public affairs duties would be spread around.

Even now, when I meet one of the Apollo 11 crew members at a social gathering or technical meeting, I sense in each of them an intangible special quality. Perhaps it is a particular confidence or presence that is borne by those who have shared a unique experience or survived dangerous circumstances. One thing is certain: Neither we nor they can ever separate ourselves from the experience and knowledge gained by making the first trip to the Moon. We can never again view the Moon with the same mystery and naive ignorance of those before us.

VII. Apollo 12 through Apollo 17

There was little time to project what we learned from Apollo 11 into planning for Apollo 12. For the next three years, a lunar mission would be carried out every six months. The scientific community would have preferred to slow down the rate of the missions in order to have time to digest the data from one mission before samples arrived from the next. Costs, however, dictated that the launches be separated by only a few months.

Apollo 12, with Conrad, Bean, and Gordon, was launched on November 14 and landed on the Moon at a near equatorial site on the relatively young basalts of the Ocean of Storms. The exact landing was within 200 yards of the Surveyor 3 spacecraft, which had landed there in April 1967 and was the nominal target point. Building on lessons learned from Apollo 11, the Apollo 12 crew stayed on

the lunar surface much longer and performed a more complex mission. Conrad and Bean made two traverses, collected several drive tube samples, dug and sampled two shallow trenches, photographed 23 panoramas, described several craters, and collected about 34 kilograms of samples, many of which were documented. In addition, they deployed a more sophisticated instrument array, including another passive seismometer and a magnetometer. Samples of the Surveyor 3 spacecraft were collected both for engineering and scientific purposes. The mission was an outstanding success. The second batch of lunar samples was on its way back to Earth weeks before detailed results from Apollo 11 were complete.

The first Lunar Science Conference was held in Houston on January 5–8, 1970. Each principal investigator was required to have a paper ready for publication at the beginning of the conference. The papers were turned in to editorial staff who were prepared to handle the publication of the results with record speed. Also, each principal investigator was required to present his or her major results in a brief oral presentation. It had been agreed that no investigator would release information about his results until this conference. Everyone would hear the results at the same time. It was the most excitement-filled scientific conference I have ever attended! Each day we learned new things and tried to fit new data into each of our personal concepts of the Moon. The results were published in a single issue of *Science*.[26]

Our laboratory at the University of Houston had done its work also, and we had one observation we believed was significant. Among the small rock fragments in the lunar soil, we found fragments of anorthosite, a generally light-colored rock composed almost entirely of calcium-rich plagioclase feldspar. We noted that this rock type was not represented among the larger rocks collected at Tranquility Base and speculated the anorthosite fragments might be broken pieces from the nearby lunar highlands. We found at the conference that three other laboratories had made the same obser-

[26]*Science*, vol. 167, no. 3918 (30 January 1970), 417–792.

vation. In addition, we concluded, "None of the glass yet examined is similar to tektite glass. This observation tends to reinforce strongly the previous conclusions of many workers that tektites do not originate from the Moon." Based on preliminary data from the Apollo 12 samples, our conclusion was challenged almost immediately.[27] I tried to ignore the paper, went on vacation, and hoped someone else would refute it. But alas, when I returned from vacation I had to write a rebuttal.[28] I consider it lucky that although our discussions of tektites, both face-to-face and in print, have been passionate, O'Keefe and I have remained good friends throughout our disagreements.

I was no longer a member of the PET. My new obligations with the university did not allow time for such work, and my ex-big boss at NASA probably would not have permitted it. I still lived in the NASA area and frequently saw many of my old friends.

During the Apollo 12 preliminary examination, a break in the biological barrier occurred in the area where the preliminary mineralogy, petrology, and geochemistry were being done. I heard the news report while driving home down the Gulf Freeway. The report listed the scientists who had been quarantined. Frondel was on the list. I pulled off the freeway, stopped at a liquor store, and bought two fifths of Canadian Club and some 7-Up, Frondel's favorite libation. I drove straight to the LRL and approached the autoclave where materials could be passed in and out of the Crew Reception Area. A technician and a guard were on duty. I knew them both. I told them I had a bag to be passed in to Professor Frondel. "What is it?" they asked. "Personal effects," I said. The technician winked his eye, and the goods were logged in as a "care" package. I later found out that another member of PET, Ross Taylor, an Australian geochemist, had hidden in the potentially contaminated area to avoid quarantine. Frondel admitted, after the fact, that being

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[27]J. A. O'Keefe, "Tektite Glass in Apollo 12 Sample," *Science*, vol. 168 (1970), 1209–1210.

[28]E. A. King, R. Martin, and W. Nance, "Tektite Glass NOT in Apollo 12 Sample," *Science*, vol. 170 (1971), 199–200.

quarantined with the Apollo 12 crew had been a memorable time and not at all unpleasant.

The basalts from Apollo 12 proved to be a little younger than the rocks from Tranquility Base, averaging about 3.3 billion years. Also, the rocks contained less ilmenite and thereby had lower titanium contents.

The launch of Apollo 13 on April 11, 1970, signaled the start of a lunar mission that nearly ended in disaster. An explosion in a fuel cell on board the Service Module seriously crippled the life support systems of the spacecraft en route to the Moon. The crew had to travel outbound around the Moon and head back to Earth. The condition of the cabin atmosphere was critical. With carbon dioxide building up in the spacecraft atmosphere and little oxygen left, only superb engineering analyses on the ground and a crudely taped-together pair of lithium hydroxide canisters on board to absorb some of the carbon dioxide from the cabin atmosphere would enable Lovell, Swigert, and Haise to make it back alive. It was a very close call.

When the Apollo 14 crew was announced on August 6, 1969, almost everyone expected Gordon Cooper to be named mission commander. Instead, Shepard was picked for the mission commander assignment. Shepard had never been a member of an Apollo back-up crew, as was customary for previous prime crew members. Cooper resigned from NASA less than a year later.

I asked my dean at the University of Houston for funds to host a cocktail party and reception for the lunar sample investigators at the Apollo 12 Lunar Science Conference. He agreed. We held the affair in the Rice Hotel in downtown Houston. It was a huge success, attended by the mayor of Houston and a number of other academic and political dignitaries. One noteworthy attendee was Russian academician A. P. Vinogradov, who was accompanied by an interpreter. Vinogradov had been invited to present a report on the preliminary results from the highly successful unmanned Luna 16 mission. Luna 16 brought back 101 grams of sample from Mare Fecunditatis (Figure 1, page 25) in September 1970. Vinogradov

made an interesting presentation at the conference and was a charming guest. We noted that both Vinogradov and his interpreter drank only orange juice, contrary to Russian tradition. We later heard that the interpreter was missing and was presumed to have defected, at least temporarily, but I never found out.

The next Apollo lunar landing occurred on the Fra Mauro Formation approximately 181 kilometers from the Apollo 12 landing site. Ed Mitchell manned the LM, together with Al Shepard, and Stu Roosa was the CSM pilot. From lunar orbital imagery, the Fra Mauro Formation was interpreted to be ejecta from the huge Imbrian Basin; therefore, it was believed to contain much older rocks than the Apollo 11 or Apollo 12 landing sites. The possibility existed of collecting some rocks from deep within the Moon that had been excavated by the Imbrian impact. This was a rougher landing site, but NASA felt confident it was a suitable site from an operational standpoint.

The crew of Shepard and Mitchell made two long traverses from the LM, one of these approximately a kilometer away to the rim deposits of Cone Crater. They were aided by a new rickshaw-like device called the modularized equipment transporter (MET), which could be used to carry samples and collection equipment. They collected approximately 43 kilograms of samples, deployed a complex suite of lunar surface experiments, conducted active surface experiments, and made numerous observations. In addition, Roosa photographed surface features of interest from lunar orbit, including the candidate Apollo 16 landing site. Many of the surface samples were well-documented and were included within the numerous surface photographs. Shepard made his famous lunar golf shot, which prompted a variety of reactions. The samples proved to be quite different from the previously collected mare samples. Most of the large samples were breccias. Only two of the rocks greater than 50 grams in weight were crystalline igneous rocks, and a big dispute arose that one of these, rock 14310, might be crystallized impact melt rather than a standard, garden-variety igneous rock.

Compositions of the rocks were distinctly different from the

basalts of Apollo 11 and Apollo 12, containing less titanium, more alumina, and less iron, on the average. Their crystallization ages averaged about 3.9 billion years, the probable age of the Imbrian event. Included in the Apollo 14 breccias were nearly spherical objects with textures that looked very much like meteoritic chondrules, except that they were of lunar origin.[29] These lunar chondrules were abundant in some samples. Together with my co-workers, I quickly prepared a paper for publication on this finding and sent it off to a major journal.

Urey was again visiting the Lunar and Planetary Institute, so while the paper was "in press," I called and made an appointment to see him. I took a slide projector and some slides of the lunar chondrules. It seemed like a small courtesy to extend to a man who had spent much of his lifetime trying to understand complex scientific issues. Urey was fascinated. We reviewed each slide several times and discussed many matters related to chondrules. We wondered what the occurrence of lunar chondrules might mean, if anything, in terms of the origins of meteoritic chondrules. Our discussion still has not been fully resolved, though most researchers now agree that at least some meteoritic chondrules are produced by impact-related processes.

In the haste and physical exhaustion of the EVAs on Apollo 14, along with confusion over which rocks were in which weigh bags, the localities from which some of the large rocks were collected have not been positively established. However, a big lunar rock is a valuable resource even if its exact field context is unknown. It was the largest and most varied suite of rock samples returned from the Moon at that time.

The automated Russian spacecraft, Luna 20, landed on the Moon in Mare Fecunditatis in February 1972. This mission also was successful in returning a small sample from a locality about five degrees latitude north of the Luna 16 landing site.

[29]For example, see E. A. King, M. F. Carman, and J. C. Butler, "Chondrules in Apollo 14 Samples: Implications for the Origin of Chondritic Meteorities," *Science*, vol. 175 (1972), 59–60.

On April 28, 1971, NASA announced that the Interagency Committee would no longer require either crew or sample quarantine on future lunar missions. All test results in search of lunar pathogens had been negative. This announcement was welcome relief. The Service Module propulsion system had proven so reliable that NASA could relax the free return trajectory constraint, meaning the crews could visit sites at higher latitudes out of the bow-tie zone. Apollo 15 landed near Hadley Rille at a latitude of approximately 26 degrees north on July 30, 1971 (Figure 1, page 25). The prime objectives of this mission were to sample the rocks of the great Apennine Front, Hadley Rille, and the mare material of Palus Putredinis on the eastern edge of the Imbrian Basin. The Apennine Front was believed to contain ancient rocks uplifted by the Imbrian event. Hadley Rille was targeted for exploration in order to understand the disputed origin of the lunar sinuous rilles. The mare material was simply the smoothest place to land, but might offer basalts of different age or petrologic type. Mt. Hadley towered above the landing site by about four kilometers. All of the sampling objectives were within reach of the Lunar Roving Vehicle (LRV), which was first used on this mission (Photo 57). The LRV was carried to the

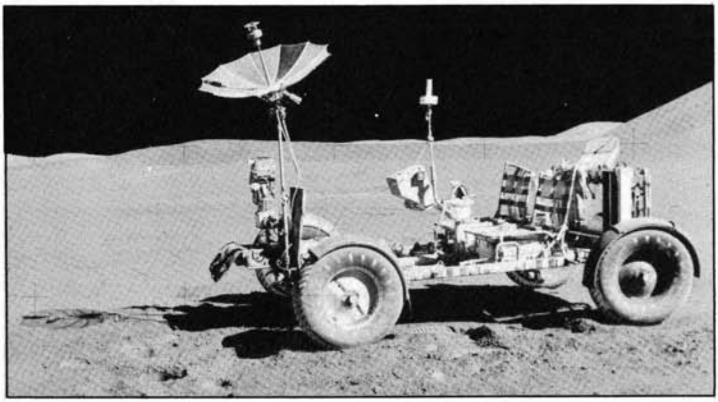


Photo 57. Portrait of the Lunar Roving Vehicle (LRV) at the Apollo 15 landing site, view looking north. The LRV carries communications, imaging, and sample collection equipment. (NASA photograph AS15-88-11901)

moon folded up in a portion of the LM descent stage. It weighed 462 pounds and could carry a payload of more than 1,000 pounds, including two astronauts. By terrestrial standards, the vehicle was a tired Jeep with a half gallon of gas, but this two-man, battery-powered vehicle with all its sampling, imaging, and communications gear made possible a much greater radius of surface exploration than was previously possible.

Scott and Irwin spent 18.5 hours of surface EVA. They collected 77 kilograms of samples, many of which were documented, deployed a complex experiments array, and took more than 1,150 photographs. An important part of the scientific data on this mission came from experiments on the orbiting CSM, piloted by Al Worden. In particular, the orbiting gamma-ray spectrometer and X-ray fluorescence experiment enabled us to extend compositional information from the rocks at the landing sites to much larger areas of the Moon.

The mare basalts from Apollo 15 proved to be almost uniform in composition, showing little range in magnesium, iron, and titanium values. The ages of the basalts were mostly around 3.3 billion years, while the ages of the Apennine Front materials tended to be about 3.9 billion years. Anorthosites were abundant in the Apennine Front samples. During a surface traverse, a peculiar green rock was noticed by the crew. This proved to be made of green glass spherules and fragments of probable volcanic origin. Green glass was a common component of the soil on the Apennine Front. Impact melt rocks also were common.

While returning to the LM to recharge his life support system, Scott said that he had a seat belt problem and stopped the LRV. A few minutes later he said it was okay and continued on. When asked about the supposed problem during the technical debriefing, Scott admitted he had noticed a rock he should collect and had used the seat belt story as an excuse to stop. Scott doubted that mission control would have allowed the stop at that point in the traverse. All in all, the Apollo 15 mission was one of the best. The crew collected a large and marvelously varied suite of rocks.

The Apollo 16 landing site (Figure 1, page 25) was selected because it was interpreted from photogeology to be composed predominantly of highlands volcanic units. This interpretation turned out to be false. Nonetheless, this was the only landing in classic lunar highlands and was of great interest for that reason alone. The Caley and Descartes Formations, which were prime exploration targets of this mission, proved to be impact-emplaced ejecta units. Shock metamorphosed materials and impact glasses were abundant in the samples. I had agreed to edit a proceedings volume from the third Lunar Science Conference,[30] but these Apollo 16 samples were already on their way back to Earth before the volume went to press.

The Apollo 16 crew performed very well. We were particularly proud of "Black Bart," a nickname earned by John Young for his favorite cowboy hat that he wore on geology field trips.

As the date for the Apollo 17 launch neared, I decided to go to the Cape for the event. It was the last lunar landing mission, the last big Apollo Saturn V configuration, a spectacular night launch, and Cernan and Schmitt would be LM crew. It all seemed to mean that I should be there. Before, I had always been too busy to get away to the Cape, but this time I was going to take the time. I couldn't find a motel room closer than Orlando, but I managed to get a confirmed rental car reservation. As the evening of December 7 approached, I stopped to get a bottle of champagne, some beer, and a big sandwich for later and drove to the Cape. I had a pass for the VIP viewing area, but the bleachers were full and didn't look very comfortable. I staked out a good-looking patch of grass and waited for "t=0" to arrive. The countdown went well in the early stages, and everyone was very upbeat. Many of the lunar sample principal investigators were there. We had a very pleasant visit, cracked jokes, and waited for the big rocket to go. There were a couple of "holds" near launch time, during which we drank all the beer and champagne. The big moment finally arrived, and the ignition and

[30]E. A. King, ed., Proceedings of the Third Lunar Science Conference, Vol. I, Mineralogy and Petrology, *Geochimica et Cosmochimica Acta, Supplement* 3 (1972).

lift-off were truly spectacular. Air pressure and sound waves from the rocket drowned out everything and buffeted us with energy. Although low clouds had hung above for most of the evening, the sky had few clouds at launch, and we could see the rocket at 85 miles down range. I could also see the first-stage cut-off and second-stage ignition. Cernan, Evans, and Schmitt were on their way to the Moon! I was on my way back to Orlando. The highway was like a big parking lot. It took four hours to get to my motel. I flew to Houston the next morning.

Apollo 17 landed in the Valley of Taurus-Littrow, approximately latitude 20 degrees and 10 minutes north and longitude 30 degrees and 46 minutes east (Figure 1, page 25). Cernan had done extremely well in the geology training course. Schmitt was a Harvard Ph.D., so it was not surprising that the mission was extremely productive scientifically. Five separate large-scale stratigraphic units were sampled, the crew made excellent surface observations, a large instrument array was deployed, and a huge suite of samples (approximately 110 kilograms) was collected during 22 hours of EVA on the lunar surface. The LRV worked very well, covering over 35 kilometers. As in previous missions, many photographs and special samples were taken, and the CSM also had a full suite of orbital experiments. At one stop, the crew recognized the now famous "orange soil," which proved to be glass of probable volcanic origin.

By now, seeing astronauts on the lunar surface had become commonplace. The major TV networks did not even offer live coverage of all the EVAs, but we had it in Houston. The local educational channel, whose facilities were on the University of Houston campus, arranged to cover the EVAs in real time. I acted as "science host" and described events to our viewers, interviewed various local NASA scientists and some principal investigators for lunar surface experiments, and gathered a panel of students who commented on various aspects of the mission. It was a lot of fun, and we received a number of favorable comments about our coverage, even though it wasn't as "slick" as national network coverage.

Suddenly, the flights of the Apollo program were over. NASA

decided to cancel Apollo Missions 18, 19, and 20, even though hardware existed and plans had been made. The decision allowed NASA to commit the hardware to Earth-orbital flights that might lead to a new large-scale program.

Scientific work on the lunar samples continued in high gear for 10 years and, as a matter of fact, continues to this day, although at a slower rate. Some of the lunar surface experiments, such as the net of passive seismometers deployed by the Apollo missions, continued to function and provide valuable data long after the landings were over. The lunar seismic data told us the Moon has a small core that is partially molten. Scientific papers about the Moon, lunar samples, and other closely related topics from Apollo now fill a shelf of books about eight feet long! Apollo missions produced an information explosion about the Moon in particular and planetary science in general.[31] We had made six highly successful manned lunar landings and sample returns on one side, the visible face, of the Moon. We had achieved the goal set by President Kennedy, and no new major goals in manned planetary exploration had been established. The United States planned no further lunar exploration.

There is a mistaken idea that the cost of the Apollo missions should all be charged to science. This is simply not true. Many factors led to the decision to go to the Moon: development of advanced technologies, competition with the Russians, stimulation of the national economy, and diversion of attention from the Bay of Pigs fiasco. Science was barely mentioned in the fine print. We got a lot of scientific data from the Apollo program, but only through the immense efforts of a few individuals against a batallion of bureaucrats. If the chief emphasis of the Apollo program had been on science, the missions would have been performed rather differently.

[31]For example, see S. R. Taylor, "Planetary Science: A Lunar Perspective," *Lunar and Planetary Institute* (Houston, 1982). For detailed technical papers on lunar sample results, see the individual proceedings of the now numerous Lunar Science Conferences.

VIII. Post-NASA

After leaving NASA, my time was divided among administrative chores as chairman of the University of Houston geology department, teaching courses in our graduate and undergraduate programs, and my own research. Along with two colleagues and several student assistants, I worked with soil samples from all the Apollo missions and regularly presented and published our results either in the Lunar and Planetary Science Conference *Proceedings* or in major journals. Sooner or later we would inevitably run out of good research ideas for the lunar samples, and we did.

For a couple of years, much of my spare time was spent preparing a textbook on the geological aspects of space sciences.[32] This

[32]E. A. King, *Space Geology: An Introduction* (New York: John Wiley & Sons, 1976).

work evolved from courses I taught at the graduate level, and it was convenient to have this material available in a single volume. However, the book soon became out-of-date as well as out-of-print. Others wrote similar texts that I used, because updating a text every few years is not an appealing task to me.

Slowly, but surely, the group began to disperse. I left the space agency shortly after Apollo 11. Warner stayed on to work on future PETs and perform a variety of research tasks, but eventually left to join an oil company research lab. Clanton continued work on lunar samples, U-2 recovery of micrometeoroids, and a variety of other topics, but finally took a job with the Department of Energy. Dietrich remained with NASA and eventually became lunar sample curator. A single interest had united us for several years, but in the end most of the Apollo group split up and went separate ways.

Meanwhile, the discovery of lunar chondrules in the Apollo 14 samples sparked my old interest in meteorites. I began to work with stony meteorites again, particularly on the origins of meteoritic chondrules, which led to a series of solar furnace experiments at a laboratory in the French Pyrenees, a marvellous location for scientific work, high in the lovely mountainous countryside only a couple of hours from the Costa Brava. The work was very productive and thoroughly enjoyable. Research showed that meteoritic chondrules were formed by more than one process. Some certainly were formed by impact-related processes, but many chondrules apparently had formed as a result of another process.[33] Many questions concerning the major process responsible for chondrule formation remain unanswered.[34]

In 1979, several researchers suggested that a small group of meteorites, the so-called "SNC meteorites" (for shergottites, nakhlites and Chassigny), might have originated from Mars (Photo 58).

[33]E. A. King, "Refractory Residues, Condensates and Chondrules from Solar Furnace Experiments," *Journal of Geophysical Research* (supplement), vol. 87 (1982), A429–A434.

[34]E. A. King, ed., *Chondrules and Their Origins*, Lunar and Planetary Institute (Houston, 1983).

SNC meteorites have crystallization ages ranging from one billion to 1.3 billion years and show highly fractionated rare earth element distribution patterns indicating a probable origin on a planetary body that was internally able to generate lava flows and associated igneous rocks for a longer time span than on the Moon. Some of the SNC meteorites were found to contain trapped noble gases and nitrogen similar to analyses of the atmosphere of Mars as determined by the Viking landers. It has been generally assumed that the SNC meteorites were launched from Mars by a large impact and arrived in an Earth-crossing orbit. The same scenario was proposed for the lunar origin of tektites, yet we knew tektites did not originate from the Moon, and we had no examples of lunar meteorites.

Only a few years later, in 1982, an anorthositic highlands breccia, Allan Hills A81005 (Photo 59), was distributed to investigators in the Antarctic Meteorite Collection Program. The breccia was recog-

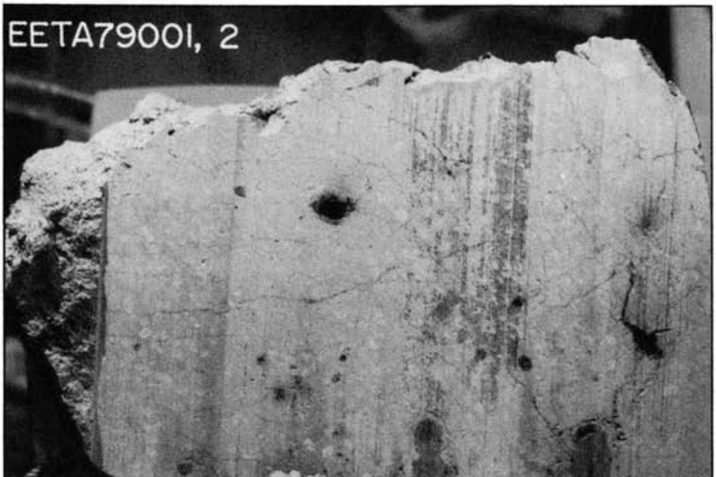


Photo 58. An "SNC" meteorite (EETA79001) collected in the Antarctic near Elephant Moraine. This and the other SNC meteorites probably originated from the planet Mars. (NASA photograph S80-37638)

nized immediately as a lunar meteorite. Its composition was very similar to Apollo 16 breccias, but it had slightly lower concentrations of potassium, rare-earth elements, and some other trace elements. The objections to the impact mechanism for launching rocks from a planetary surface without totally melting them were no longer realistic, especially considering that an additional five lunar breccia samples were recognized in Antarctic meteorite collections by the Japanese. Everyone had looked for pieces of the Moon in the meteorite collections before the Apollo landings, but the right samples were not collected until after Apollo. It now appears likely, however, that we have recognized pieces of Mars well in advance of a sample return from that planet.[35]

In the mid-1970s, Russian investigators recognized an impact structure in southern Siberia, the Zhamanshin crater. Located about 200 kilometers north of the Aral Sea, the crater has abundant tektites (Photos 60, 61, 62) and shows evidence of associated shock

[35]For example, see M. R. Smith, J. C. Laul, M. S. Ma, T. Huston, R. M. Verkouteren, M. E. Lipschutz, and R. A. Schmitt, "Petrogenesis of the SNC (Shergottites, Nakhlites, Chassignites) Meteorites: Implications for Their Origin from a Large Dynamic Planet, Possibly Mars," *Journal of Geophysical Research* (supplement), vol. 89 (1984), B612–B630.

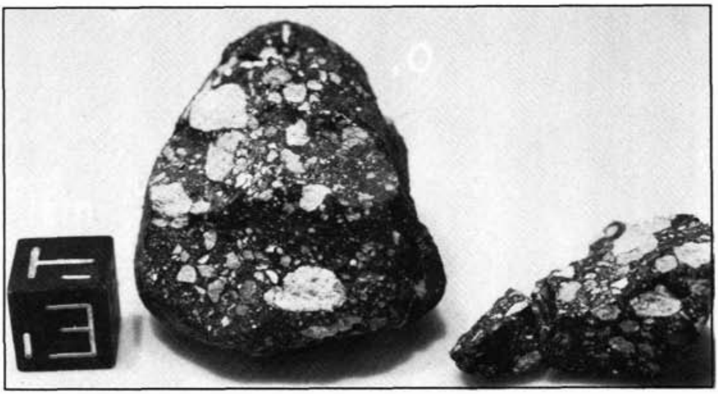


Photo 59. Antarctic meteorite collected near Allan Hills (ALHA81005) that is a fragment of the regolith from the highlands of the Moon. Several such lunar meteorites have now been recognized in the Antarctic meteorite collections. (NASA photograph S82-35867).

metamorphism.[36] Zhamanshin is a small crater, only about 10 kilometers in diameter. The tektites formed by the impact event do not possess all the properties of previously known tektites. Although some are identical to other tektites under the microscope, they contain more water, intermediate between other tektite glass and obsidian, and have a lower ferrous to ferric iron ratio.[37] In summary, the Russian tektites (Irghizites) are a beautiful link between the impact products of small and large impact craters. Had the Irghizites been one of the first groups of tektites studied, the whole argument about the origin of tektites probably never would have occurred.

Before, during, and after the Apollo program, unmanned plane-

[36]P. V. Florensky, "The Zhamanshin Meteorite Crater (the Northern Near-Aral) and Its Tektites and Impactites," Izvestiya of the Academy of Sciences of the U.S.S.R., Geologic Series, no. 10 (1975), 75–86.

[37]E. A. King and J. Arndt, "Water Content of Russian Tektites," Nature, vol. 269, no. 5623 (1977), 48–49.

Photos 60, 61, and 62. Russian tektites (Irghizites) from the Zhamanshin Crater north of the Aral Sea. Maximum length of specimens is approximately two centimeters. (Photographs by the author)

tary missions were launched to various planets. These launches occurred at irregular intervals and included fly-bys, orbiters, and landers. I began to look at the data from these missions, particularly the images. An early Mars fly-by mission, Mariner 4, obtained a limited set of poor-quality images from the planet. These images indicated the body was cratered terrain, much like the lunar highlands. The evidence was disappointing because we had hoped to find a more active planet. Mariner 6 and Mariner 7 broadened our view of the surface considerably, but it was not until the Mariner 9 Mars orbiter and Viking orbiters that we realized the full range of geological processes that has shaped the exceedingly varied surface features. The chief differences between the Moon and Mars derive from the larger size of Mars—large enough to remain internally active for much longer than the Moon—and the presence of abundant volatile elements and compounds such as water. Surface analyses from the Viking landers indicate a soil that is very different from lunar soil, probably due to interaction with the atmosphere and other volatiles. Chemical weathering of Mar's surface rocks has played a very important part. The variety of terrains and surface features is tremendous, ranging from huge canyons to giant inactive volcanoes, icy polar caps to desert dunes, relatively recent low flat desert to ancient densely cratered uplands. Involved in a Mars geologic mapping project, I produced a photogeologic map of a Mars quadrangle at the scale of 1:5,000,000[38] on a base made from Mariner 9 imagery. When I joined the Mars Geologic Mapping Program, I discovered that a former schoolmate, Carroll Ann Hodges, who had attended high school and college with me, had applied for the program, too.[39] Later, another high school and college friend, Joachim Meyer, who was on the Tulane University faculty, joined the program. Still another old classmate from the Uni-

[38]E. A. King, "Geologic Map of the Mare Tyrrhenum Quadrangle of Mars," USGS Map I-1073 (MC-22) (1978), with text.

[39]Caroll Ann Hodges had worked for the U.S. Geological Survey, Branch of Astrogeology, Menlo Park, Calfornia. She worked on many aspects of lunar and martian geology, particularly image interpretation, and later went into administration.

versity of Texas, Jim Underwood, who had joined the Kansas State University faculty, was selected to participate in the planetary mapping. He is now serving a term at NASA Headquarters as program scientist for the mapping program. The geologic mapping project forced me to examine the imagery seriously so I could compare features of the Moon and Mars.

Mariner 10 managed to fly by Venus and collect some data, but its chief accomplishment was imaging approximately half the surface of Mercury. Mercury proved to be relatively dull, with a cratered surface revealing little evidence of a geologically active history. Like the Moon, Mercury lacks an atmosphere and appears to be barren of volatiles. I collaborated with a colleague to produce a photogeologic map of a portion of the surface of the planet.

Venus has been the target of a long series of Soviet spacecraft. The Soviets have been very successful in landing probes on the hot surface (approximately 450 degrees Centigrade) and making measurements and taking images. The first image from the surface of the planet was taken by the Venera 9 lander in 1975. During December 1978, however, 10 separate unmanned spacecraft were hurled at Venus, including both U.S. and Soviet efforts. Seven of these craft entered the dense atmosphere (approximately 92 times the pressure of the Earth's atmosphere at the surface) and took various measurements. Venera 11 and Venera 12 landed instrument packages on the surface. The U.S. Pioneer Venus Orbiter contained a radar experiment which permitted low-resolution topographic mapping of about 90 percent of the surface through the dense cloud cover that permanently surrounds the planet. Later, Venera 13 and Venera 14 obtained surface imagery, surficial analyses by X-ray fluorescence indicating two different types of basalt. Later missions obtained orbital radar imagery of a large portion of the Venusian surface. Based on radar image interpretations, both impact craters and large volcanic features have been identified. Although Venus is nearly the Earth's twin planet in size and density, Venus apparently has not experienced active plate tectonics. It seems the relatively rigid Venusian lithosphere is too thin for plate tectonics, and something

more like "scum tectonics" has occurred. Although an interesting and dynamic planet, the tough temperature and pressure environment on the surface indicates Venus will remain in the realm of unmanned spacecraft and robots for a long time. Even an automated sample return from Venus appears extremely difficult with current technology.

The Soviet Union continued automated sample returns from the Moon with the Luna 24 Mission in August 1976, which returned a core 160 centimeters long from Mare Crisium on the Moon's eastern limb. Under a joint agreement with NASA, the Soviet Academy of Sciences provided U.S. scientists with three grams of soil for scientific study, which resulted in a substantial volume.[40] The basalts from Mare Crisium were found to be derived from two potassium and titanium depleted magmas, one of which has twice the magnesium oxide content of the other.

The clouds of Jupiter and the surfaces of the four Galilean Satellites were beautifully imaged by Voyager I and Voyager II. Io, with its orange, sulfur-rich surface, lack of impact craters, and more than 10 active volcanoes, is unique. Europa also lacks impact craters and has a surface probably composed of dusty ices. Ganymede's surface shows the effects of many impacts and relative movements of large segments of icy crust. Callisto is covered with small- to intermediate-sized impact craters. Four adjacent satellites—each different from the other! For these planetary bodies we have a few images, but little other information.

Voyager I continued on to the Saturnian System, with Voyager II close behind. The chief data of geologic interest were the images of the 15 moons of Saturn. The moons proved to be mostly water ice with varying numbers and sizes of craters and some dull surface differences in albedo, probably due to dust or silicate rocks. Although the images are dramatic, few other data exist.

The European Space Agency (ESA) accomplished a beautiful

[40] R. B. Merrill, ed., "Mare Crisium: The View from Luna 24," *Geochimica et Cosmochimica Acta* (supplement 9, 1977).

mission to Comet Halley. The agency obtained excellent images and some data on the composition of cometary dust that was of geologic interest. I was particularly interested because I had searched Antarctic ice cores for particles of cometary dust. Although I found a number of extraterrestrial particles, I was unable to prove that any of them were cometary.

The Skylab Program used up most of the leftover Apollo hardware with three successful flights. An orbital-rendezvous mission with the Soviets accomplished little of scientific interest.

In April 1981, the first space shuttle hurtled off the launch pad, and shuttle missions continued at the rate of two or three per year until the mid-'80s. Although these missions could not visit other planets, they were the means by which some important instrument packages and deeper space missions were sent as far as low Earth orbit. Then, on January 28, 1986, the launch of the *Challenger* orbiter ended in disaster. The immediate effect of this tragedy was a 32-month suspension of U.S. manned space flight, while there was a substantive redesign of many shuttle parts and procedures. The U.S. returned to space in the fall of 1988 with the highly successful *Discovery* orbiter flight. However, the total effect of the *Challenger* failure may depend on the degree of success of subsequent shuttle flights. On November 14, 1988, the Soviets accomplished a successful unmanned orbital test flight of their shuttle-like spacecraft. The Soviet shuttle can accommodate more flight crew and lift heavier payloads into Earth orbit than the American shuttle.

The space station as currently planned, even if completely successful, will do little for our exploration of other planetary bodies. The Strategic Defense Initiative (SDI) remains a large unknown. Extensive deployment of defensive weapons systems might lead to considerable ability to lift large payloads into low Earth orbit, enabling the assembly of interplanetary missions which could be launched from that position. SDI itself, however, will be primarily an inward-looking program.

A proposal to "return to the Moon" by establishing a lunar base for scientific or resource extraction purposes has received a consid-

erable amount of attention,[41] but is a long way from authorization and funding.

Various study groups have been convened by NASA, the National Academy of Sciences, and the White House, including a National Commission on Space. None of the reports of these various groups assumes a bold leadership position, and it appears the reports will not serve as a blueprint for the exploration of space in coming decades. There is little evidence to indicate that any of the recommended sequences of missions will be translated into action.

A "National Space Policy," signed by President Reagan,[42] will direct us toward the Moon and Mars with coming studies. However, it remains to be seen if this direction will be maintained by subsequent administrations and whether sufficient funding will be forthcoming.

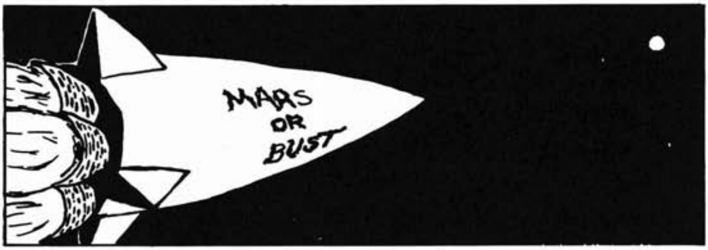
At this time, the future of U.S. space exploration must be considered exceedingly uncertain. We appear to lack the resolve to make decisions. If we do not choose to be a leading spacefaring nation, let us make that choice consciously and clearly, not simply by lack of action.

The Soviets have decided to continue supporting a strong space program, and they have sustained an enviable program of both manned and unmanned space flight. The Soviet "Mir" space station has set long-term human orbital flight records. These long duration space flights serve to qualify Soviet life support systems for manned deep space missions. Representatives of the U.S.S.R. have announced an ambitious program for the unmanned exploration of Mars and its moons, and it is widely speculated that they may fly a manned mission to Phobos or Deimos within the decade. The red planet itself may be targeted for manned exploration before the end of the century.[43]

[41]For example, see W. W. Mendell, ed., "Lunar Bases and Space Activities of the 21st Century," Lunar and Planetary Institute (Houston, 1985).

[42]"President Signs Space Policy Backing Lunar, Mars Course," *Aviation Week & Space Technology* (Jan. 18, 1988), 14–17.

[43]For example, see J. E. Oberg, *Mission to Mars* (Harrisburg, Pennsylvania: Stackpole Books, 1982).



Epilogue

Virtually all we do in space is but a prelude to manned exploration and habitation of Mars (Photo 63). Nearly every study of our future space activities agrees that Mars is the ultimate goal. The reasons for this are simple—of all the planets and moons that orbit our sun, Mars is the most like Earth. It has the volatiles that are lacking in the Moon. Its position in the solar system results in surface temperatures not much colder than those on some portions of the Earth. The thin atmosphere diffuses light, helps even out thermal anomalies, and provides a source of water. The polar caps hold great reserves of water, and similar resources may be present in the shallow subsurface of lower latitudes. Like the Earth, Mars has had a long and active geologic history, providing a variety of processes that might concentrate elements and minerals in usable resource deposits.

Unmanned exploration of Mars already has resulted in a large body of data about the planet.[44] The United States has explored Mars with eight spacecraft, including three fly-bys, two orbiters, and two landers. The Russians have sent a number of probes to Mars in the past and have announced an aggressive program for

[44]For details on Mars' environment, see "Scientific Results of Viking Project," *Journal of Geophysical Research*, vol. 82 (1977), 3959–4681; *Journal of Geophysical Research*, vol. 84 (1979), 7909–8544; and *Journal of Geophysical Research*, vol. 87 (1982), 9715–10,306.

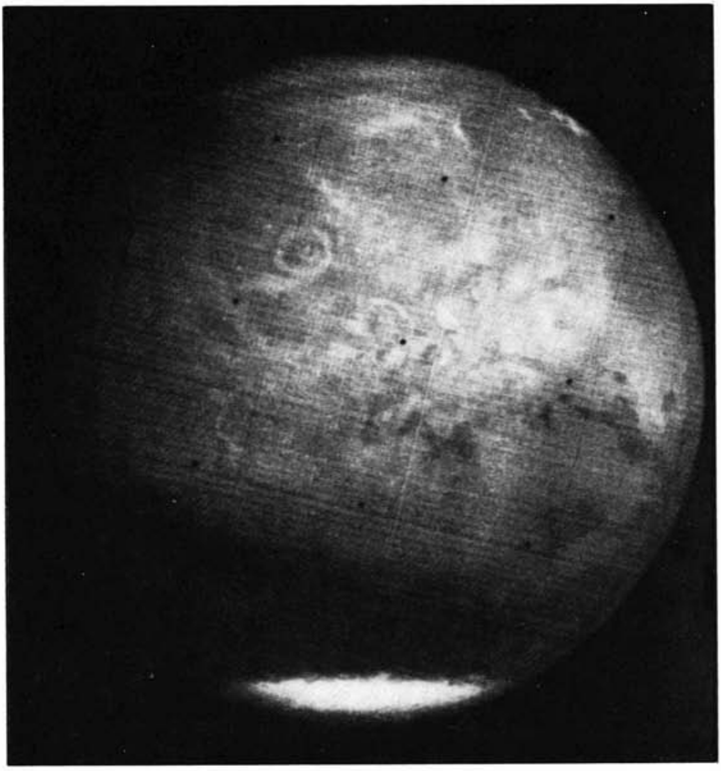


Photo 63. Image of Mars taken by the Mariner 7 spacecraft at far encounter, approximately 471,750 kilometers. North is at the top. The southern polar cap is distinct, as are many light clouds in the central latitudes. The ring-shaped structure at the upper left is the giant volcano Olympus Mons (see Photo 66). (Courtesy of NASA Jet Propulsion Laboratory)

future Mars exploration. We already know more about Mars than we did about the Moon when the United States committed to the lunar program. Let us consider the attractive features of Mars.

Atmosphere: Mars has a dynamic, thin atmosphere composed chiefly of carbon dioxide (about 95 percent), nitrogen (about 3 percent), argon (about 1.5 percent), with minor amounts of oxygen, carbon monoxide, and water vapor and trace amounts of neon, krypton, xenon, and ozone.[45] The average total atmospheric pressure over the planet is approximately six millibars. Of particular interest is the water vapor, which comprises about 0.03 percent of the atmosphere but is seasonally variable, meaning that modest amounts of water can be extracted from the atmosphere everywhere on the surface of the planet. Also, the density of the atmosphere is adequate for aerobraking of spacecraft arriving at Mars, such that missions from Earth can conserve fuel and total launch weight. The density of the atmosphere is sufficient to protect surface explorers and equipment from micrometeorites and larger incoming meteoroids of as much as several hundred grams. The easy availability of carbon dioxide and water makes agricultural activities relatively simple. Mars' atmosphere is dynamic and generates clouds, including convective clouds, wave clouds, orographic clouds, and fogs. Frosts commonly form on its surface at night. Martian clouds mostly are composed of water ice, but at high altitudes and in the polar regions, temperatures can be cold enough to produce frozen carbon dioxide.

Winds are a common occurrence in the Martian atmosphere. The maximum wind velocity measured by the Viking landers was only 16 meters per second, although winds as much as 100 meters per second have been inferred from measurements of cloud movements. Dunes and other wind erosion and deposition features are present on the surface.

Surface Temperatures: Our best measurements of surface tem-

[45]T. K. Owen, D. R. Rushneck, J. E. Biller, D. W. Howarth, and A. L. Lafleur, "The Composition of the Atmosphere at the Surface of Mars," *Journal of Geophysical Research*, vol. 82 (1977), 4635–4639.

peratures come from the Viking landers, which found a mean summer temperature of about –60 degrees Centigrade at both landing sites, with a diurnal range of about 50 degrees. During winter at the Viking 2 landing site, however, the temperature reached –120 degrees Centigrade, cold enough to condense carbon dioxide. Compare these temperatures with the Earth's South Pole, which has a mean annual temperature of about –50 degrees Centigrade, and in August 1960 recorded a low temperature of –88.3 degrees Centigrade. However, it has been calculated that on the Martian equator on a midsummer day, temperatures may reach 20 degrees Centigrade.

Polar Caps and Permafrost: Due to the eccentricity of Mars' orbit, the southern polar cap is, at maximum extent, much larger than the northern polar cap. The caps are composed mostly of water ice with a minor amount of carbon dioxide that vaporizes quickly during the spring. Thus, the summer caps are composed almost entirely of water ice, which is stable at much higher temperatures than the carbon dioxide (Photo 64). It has been estimated that an amount of water equivalent to a layer of ice 80 to 160 meters thick

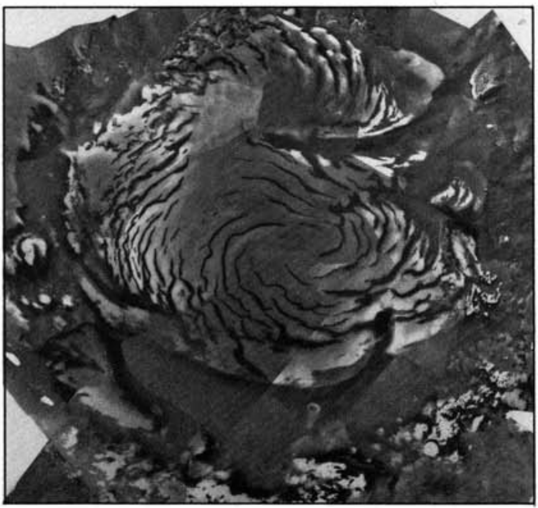


Photo 64. Viking Orbiter image mosaic of Mars' northern polar cap. (Courtesy of U.S. Geological Survey, Branch of Astrogeology)

covering the whole planet has been outgassed by Mars.[46] Many researchers believe the Martian regolith, the near-surface fragmental layer of the planet, may contain very large quantities of permafrost, based on similarities in patterned ground and other features common to cold areas on Earth, although this remains to be demonstrated by direct measurement. Many erosional features on the surface of Mars appear to be the products of running water (Photo 65); hence, there may also be much water bound in hydrous minerals in the Martian regolith. With the data already in hand, a shortage of water ice and water vapor on Mars does not exist as it does on the Moon.

Size and Rotation: Mars' greater size, about twice the diameter of the Moon, has resulted in a more geologically active planet. The great volcanic constructs (Photo 66) are similar to smaller volcanoes seen in the ocean basins of Earth, but are not recognized landforms on the Moon. The fact that Mars has been more active means that it has had additional opportunities to produce a variety of materials—i.e., certain types of ore deposits. The rapid rotation rate of Mars, about the same as Earth, helps produce some weather and

[46]J. B. Pollack and D. C. Black, "Implications of the Gas Compositional Measurements of Pioneer Venus for the Origin of Planetary Atmospheres," *Science*, vol. 205 (1979), 56–59.

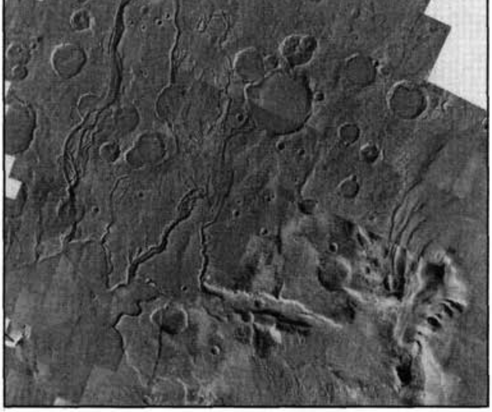


Photo 65. Image mosaic of a portion of Mars' surface showing numerous small channels probably produced by the surface and shallow subsurface movement of water. Field of view diameter is approximately 300 kilometers. (Courtesy of U.S. Geological Survey, Branch of Astrogeology)

provides a familiar day/night cycle, which would require minimium adaptation for humans. The mass of Mars produces a gravitational field on the planet's surface that is about 0.4 that of the Earth, a comfortable working environment.

Surface Materials Diversity: Images of the surface indicate that both volcanic and impact processes have been prominent in shaping the martian surface. In addition, water- and wind-sculpted features are common. Surface sediments of eolian origin, such as dunes and drifts, are abundant in some areas. It is possible that water-layed sediments are common, and even evaporites and carbonates have been suggested as possibilities. A diverse suite of surface materials is available for use as local resources.

Phobos and Deimos: Mars' two small moons offer sites as way-stations that may figure prominently in exploration strategies. Present data, such as density and albedo, strongly suggest these bodies are composed of carbonaceous chondrite, a meteorite type rich in water and other volatiles, including organic compounds. These moons also may be sources of valuable expendables for missions to Mars.

Scientific Interest: Paramount among scientific questions still to

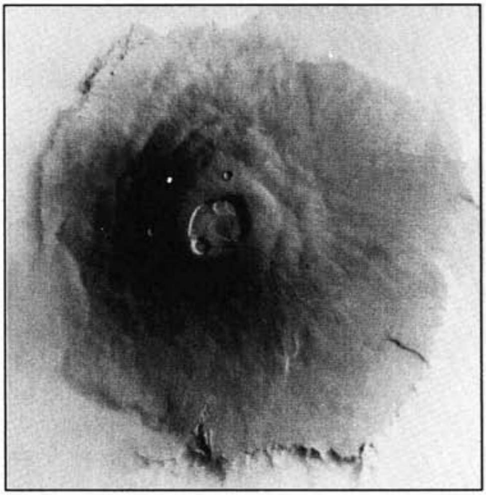


Photo 66. Composite Viking Orbiter image of the giant martian volcano Olympus Mons. The summit of the volcano rises about 26 kilometers above the surrounding plains, and the base of the mountain is approximately 500 kilometers in diameter. (Courtesy of NASA Jet Propulsion Laboratory)

be answered about Mars is whether there is or has been life on the planet. The answer to this question was not provided by the Viking landers, nor could it have been unless the evidence had been unequivocally positive. Absence of proof is not proof of absence! Planetary scientists are eager to establish Mars' geological and climatological history and to compare it with those of the Earth and Moon. The geoscientists, of course, want to examine the widest possible variety of martian rocks to determine what internal and external processes have shaped Mars and to what extent. The interactions of the atmosphere with the regolith and the polar caps offer many interesting questions. Exploration of Phobos and Deimos will be scientifically exciting as well. There is no more interesting object in the solar system than Mars and its moons.

Accessibility: Launch and return opportunities for Mars occur far less frequently than for the Moon. Furthermore, one-way transit time to Mars from the Earth takes about 170 days on minimum energy trajectories. Total mission times of two to three years are presently envisioned using conventional chemical rocket propulsion. Missions to Mars are thus long and difficult journeys. Furthermore, visitors would experience a bleak, cold, and probably barren sphere. Nonetheless, resources such as water and other volatiles are easily available and can be utilized to replenish mission supplies. In terms of total propulsion energy, a properly designed visit to a moon of Mars and a return can require less energy than a mission to the surface of the Moon and back.[47] A series of unmanned missions must necessarily precede human trips to the red planet, but these missions are within the abilities of present technology. Human trips to the moons of Mars or to the surface of Mars itself need not be delayed for three or more decades, as advocated by some studies.

If we are to participate in the early phases of manned exploration of Mars, we must collaborate with the Soviets. The new space race

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[47]For example, see E. A. King, "Mars: The Next Major Goal?" *Lunar Bases and Space Activities of the 21st Century*, W. W. Mendel, ed., Lunar and Planetary Institute (Houston), 795–799.

is already under way, and we are far behind. Such a collaborative program is not unrealistic. An increasing tendency to collaborate on unmanned Mars' missions can be seen, and the Soviets have, in fact, invited us to participate with them in an international effort to send human explorers to Mars.[48] Not only would such a large joint effort result in a historic and important technical and scientific achievement, but the project could be instrumental in beginning a period of much improved Soviet-American relations. If both countries reduced their military spending appropriately, funds might be profitably spent on a joint program of unmanned and manned Mars' exploration that would stimulate high technology industry in both countries. Similar ideas expressed by Carl Sagan, Jack Schmitt, and Brian O'Leary have met with considerable public support.

Alternatively, we might choose to proceed more slowly by ourselves, planning to arrive at Mars around 2010 with an expedition that is prepared to be the nucleus of a permanent colony. Thus, we are simply redefining what it takes to win the race to Mars. However, if we choose this option, a visionary political decision must be made very soon.

A statement commonly made is that a "return to the Moon" will somehow aid in eventually sending humans to Mars. I very much doubt the logic of this suggestion. The proponents of the Moon-focused space initiative cite the possible production of liquid oxygen from the Moon, but this would require surface mining and a complicated and potentially dangerous chemical reaction, such as the reduction of ilmenite with hydrogen to produce water and oxygen, with the hydrogen being recovered and reused. All of this would have to be accomplished in a hostile, volatile-poor environment. I believe this choice would result in an exceedingly expensive lunar program that might succeed only in using more than enough time and money required for the execution of the early stages of a manned Mars program. While there are good scientific reasons to visit the Moon again, and even if it were possible to harvest re-

[48] L. Jaroff, "Onward to Mars," *Time* (July 18, 1988), 46–53.

sources from the lunar surface, we must not be distracted from the choice exploration target of our solar system—Mars!

The excitement of the Apollo program was that it accomplished a bold leap from the surface of the Earth to the Moon. The deed challenged our technology and engineering skill. Deliberate preparations are being made now for another and even more daring leap. When it comes, I dearly hope the United States will lead in the endeavor. We must!

About the Author

Dr. Elbert A. (Bert) King is professor and former chairman of the Department of Geosciences at the University of Houston, where he has been a full-time faculty member since 1969. He joined the NASA Johnson Space Center in 1963, where his duties for the next six years included monitoring hardware developments, astronaut training, research with meteorites and tektites, mission planning, preparation for the receipt and scientific investigation of lunar samples and numerous other tasks. He was the first Curator of Lunar Samples and was a member of the Lunar Sample Preliminary Examination Team for Apollo 11. Dr. King performed scientific investigations on samples from all the Apollo missions. He is tue author of more than 100 technical papers and articles, as well as the textbook *Space Geology*. He has served on numerous NASA scientific committees and advisory groups. He is the recipient of a special commendation from the Geological Society of America and is a Fellow of the Meteoritical Society. Dr. King earned his Ph.D. degree in geology from Harvard University and holds undergraduate and master's degrees in geology from the University of Texas at Austin.